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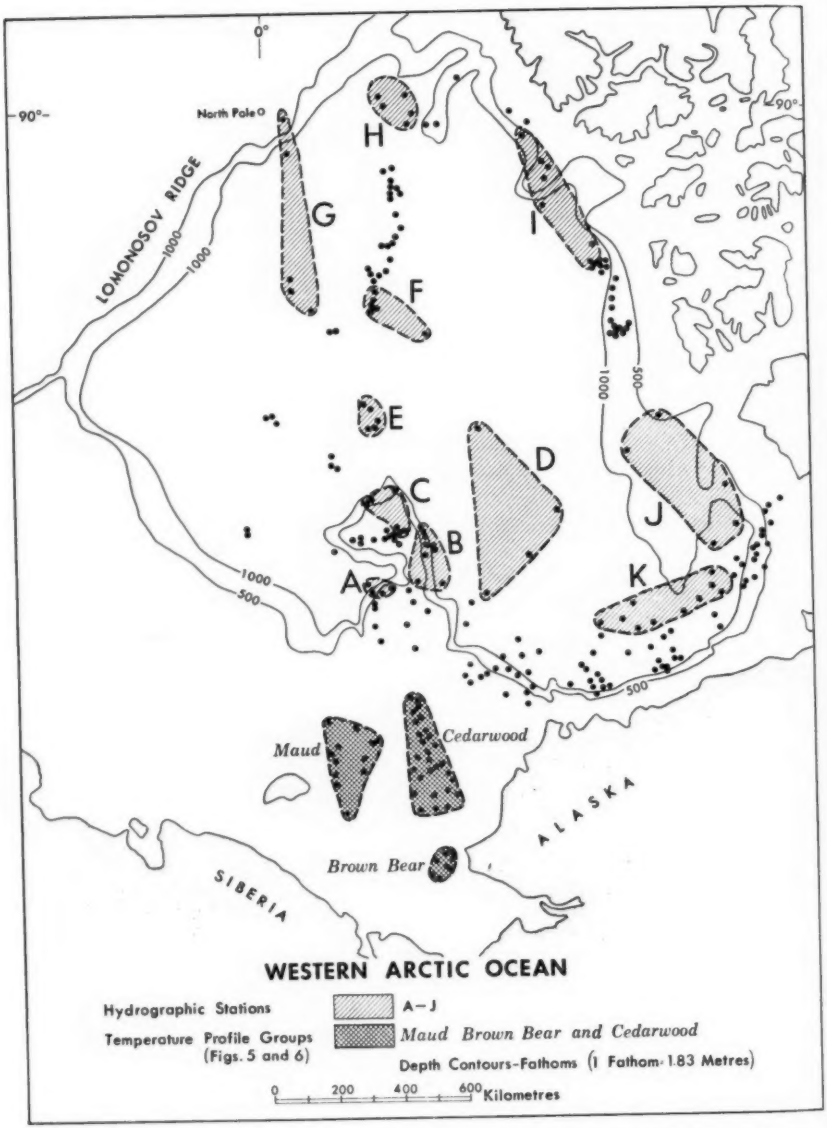


**Fig. 1.** Oceanographic stations and station groupings in the western Arctic Ocean.

# THE CONTRIBUTION OF BERING SEA WATER TO THE ARCTIC OCEAN*

**L. K. Coachman and C. A. Barnes†**

WATER from the Bering Sea flows north through the narrow (74 km.) and shallow (45 metres) Bering Strait into the Arctic Ocean. The earliest measurements of this flow were made in the summers of 1932, 1933 (Ratmanov 1937) and 1934 (Barnes and Thompson 1938) and were later extended to include the winter season by Maksimov (1945). Measurements in recent years (Bloom 1956, Fleming 1959) confirm the general pattern of flow through Bering Strait established by the early workers.

According to these measurements, the transport of Bering Sea water to the north is about 1.4 million cubic metres per second in summer, and about one-fourth to one-third of this in winter. Thus the yearly average input to the Polar Basin may be estimated at $1 \times 10^6$ m.$^3$/sec., which is in agreement with a recent Russian estimate of 37,500 km.$^3$/year (Treshnikov 1959a). This amount of water is ten times that introduced annually into the Arctic Ocean by all large Siberian rivers (Antonev 1957, Treshnikov 1959a). If this water entered the Arctic Ocean in a layer 100 metres thick without mixing, it would occupy a strip 100 miles wide from the Chukchi Sea to the North Pole.

What happens to this water in the Polar Basin? The Russians have stated that Pacific water may be traced to the North Pole, but no substantiating evidence has been offered (Treshnikov 1959b). In what manner does the Bering Sea water enter the Arctic Ocean and how may it be traced? What role does it play in modifying the surface water, deeper water, and ice cover?

We have examined about 200 deep-water (off-shelf) oceanographic stations located in the western part of the Arctic Ocean (Fig. 1 and Table 1). For the purposes of this study the western Arctic Ocean is taken to comprise the two basins, Canadian and central (LaFond 1960), farthest removed from the Atlantic. This area is bounded by the Lomonosov Ridge,

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† Department of Oceanography, University of Washington.

the Canadian Arctic Archipelago, Alaska, and Siberia. There is a concentration of stations in the area immediately north of Alaska because of extensive sampling from icebreakers. The rest of the stations were occupied from drifting ice and lie primarily around the perimeter of the Beaufort Sea. There is a paucity of observations from the interior of the Beaufort Sea and from the sector north of Siberia; only stations made from aircraft are available in these areas: the "Ski Jump" stations in the interior of the Beaufort Sea, and those made by the 1941 Russian expedition to the "pole of inaccessibility" north of Siberia.

Even though these data cover many years and all seasons of the year, there is a remarkable regularity in the vertical distribution of temperature and salinity. [It should be noted that at the rather uniformly low temperatures of the water in the Arctic Ocean the distribution of density so closely parallels that of salinity, that the latter can normally be used as an index of the mass distribution.] The variations that are observed from station to station apparently depend to a greater degree on geographic location within the basin than on secular variations. This implies that the Arctic Ocean is dynamically in a steady state and that the observed distribution of properties is a result of continuing processes within the basin.

**Table 1.** Deep-water oceanographic stations used in this analysis.

| *Station or vessel* | *Number of stations* | *Source* |
|---|---|---|
| *Fram* (1894) | 1 | Nansen 1902 |
| North Pole-1 (1938) | 1 | Shirshov 1944 |
| SSSR-N-169 (1941) | 9 | A.N.-I.I. 1946 |
| North Pole-2 (1950-1) | 16 | Somov 1954-55 |
| *Burton Island* (1950) | 35 | U.S.N.H.O. 1954 |
| *Burton Island* (1951) | 45 | U.S.N.H.O. 1954 |
| Ski Jump (1952-3) | 8 | Worthington 1953 |
| T-3 (1952-5) | 11 | Worthington 1959 |
| North Pole-3 (1954) | 2 | Treshnikov and Tolstikov 1956 |
| Ice Skate Alpha (1957-8) | 8 | Farlow 1958 |
| Ice Skate Bravo (1957-8) | 6 | Farlow 1958 |
| Ice Skate Alpha (1958) | 29 | English |
| Ice Skate Bravo (1958) | 21 | Collin 1959 |
| Ice Skate Alpha-2 (1959) | 23 | Gast 1960 |
| T-3 (1959) | 7 | Kusunoki 1959 |
| T-3 (1959-60) | 8 | Muguruma 1960 |

Fig. 2 presents curves of temperature and salinity to show the vertical distribution of these properties at various localities in the Polar Basin. In general, the Arctic Basin contains three water masses:

(1) The surface layer (Arctic Water) has varying characteristics, but is generally cold (at or near the freezing point); it is relatively dilute at the surface but below about 50 metres the salinity increases sharply with depth.

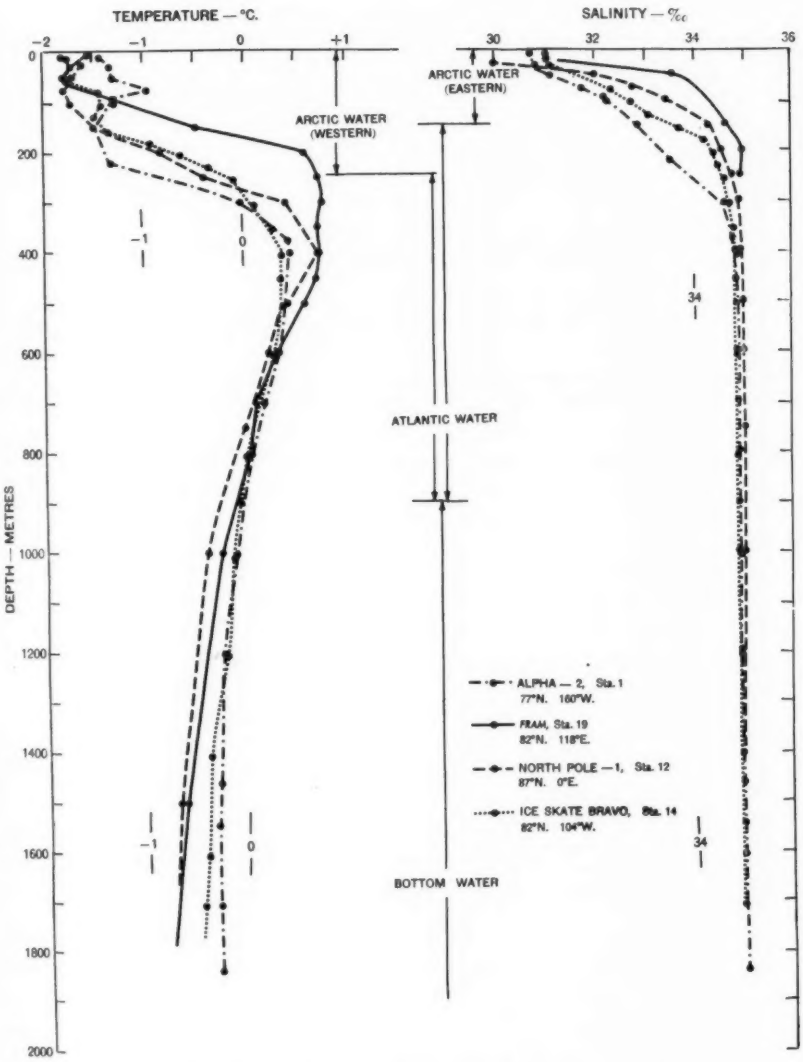



**Fig. 2.** Vertical distribution of temperature and salinity for four stations.

(2) The layer immediately below the Arctic Water, from about 150–250 metres down to 900 metres, has temperatures above 0°C. and quite uniform salinity (34.5–35.0 ‰). This water is undoubtedly of Atlantic origin (Nansen 1902, Timofeyev 1957a, 1958).

(3) Below this intermediate water layer lies bottom water with temperatures below 0°C. and with extremely uniform salinities between 34.93 and 34.99 ‰. This water is also of Atlantic origin, but apparently is formed only during winter and only in limited geographic areas in the Norwegian Sea (Sverdrup 1956, Timofeyev 1957b, Metcalf 1960).

In Fig. 2, two stations are from the eastern basin (*Fram*, Sta. 19 and North Pole-1, Sta. 12), and two from the western basin (Alpha-2, Sta. 1 and Ice Skate Bravo, Sta. 14). Even though the vertical distribution of temperature and salinity is generally similar throughout the Polar Basin, there is one notable difference between the two basins in the vertical temperature structure of the surface layer. The water in the western basin has a subsurface temperature maximum at 75–100 metres depth. This maximum may be strongly developed, with temperatures 0.5° to 1.0°C. higher than the water immediately above or below it (Alpha-2, Sta. 1), whereas in other areas it may be only barely discernible (Ice Skate Bravo, Sta. 14). This shallow temperature maximum was found in all seasons and years represented in the data from the western basin; there is, however, no evidence of its presence in the eastern basin, so apparently the degree to which it is developed depends on the locality.

In order to show that this shallow temperature maximum is indeed the effect of Bering Sea water, we must first discuss the circulation of Arctic Water in the western basin. The extensive current and ice-drift measurements made from the Russian drifting station North Pole-2 show that for the major part of the drift the ice and the water at 10 metres moved in a similar direction and with similar velocities. Hence the movements of the upper layers of water may be inferred from the movement of the numerous Russian and American drifting ice stations and of vessels such as the *Fram* (Fig. 3).

The drift of the ice island T-3, which has a deep draft (40 to 50 m. in contrast to 2 to 3 m. for ice floe stations), might be more nearly indicative of the circulation of a thicker layer of water because it is likely to be less influenced by direct wind stress. However, the drift of T-3 has been similar to that of other drifting stations in the same area, from which it may be inferred that the surface layers move as a unit. This is confirmed by the Russian current measurements previously cited.

The observed uniformity of temperature and salinity in time has allowed us to calculate the dynamic topography of the western basin (Fig. 4). The calculations were based on the 1200-decibar surface taken as the reference surface (assumed level of no motion), and were not carried to the sea surface but to the pressure surface of 25 decibars to avoid any seasonal influence affecting the very surface layers. The resulting topography agrees very well with the topography estimated by Worthington (1959) and with two topographies calculated by Russian workers from much more nearly synoptic data (Gudkovich 1959).

The circulation implied by the dynamic topography is in excellent agreement with the observed drift of ice, both as to direction and velocity. The upper layers circulate anti-cyclonically around the Beaufort Sea, with velocities of 1–5 cm./sec. around most of the gyral and with rather greater velocities (10 cm./sec.) immediately north of Alaska. Farther to the west (north of Siberia) north-flowing water does not necessarily enter the gyral but flows past the North Pole towards the east Greenland current.

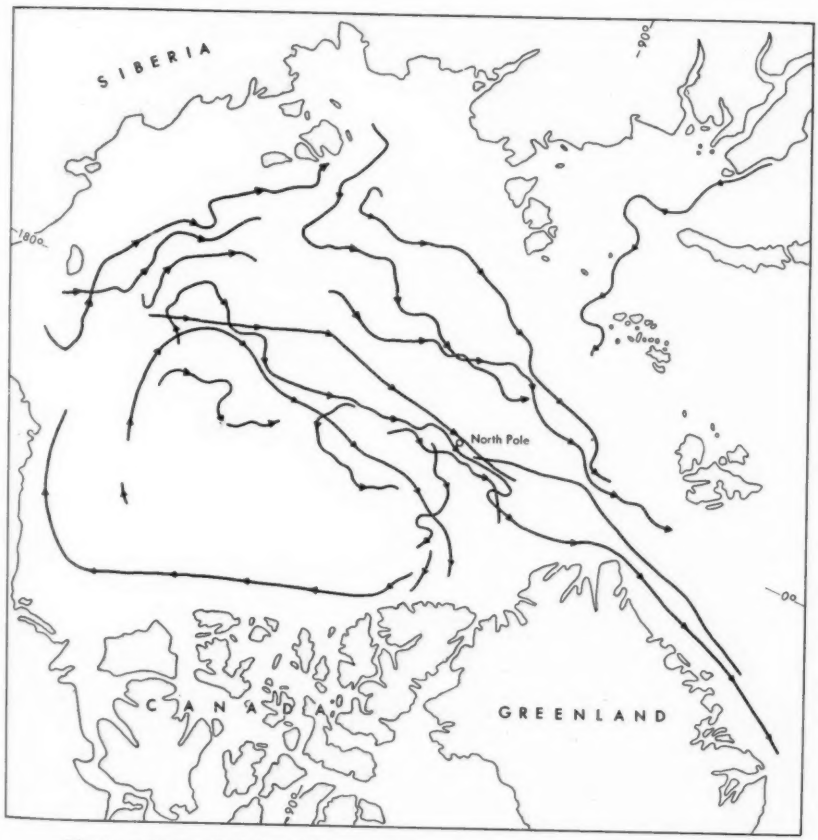



**Fig. 3.** Observed drift of floe stations and vessels in the Arctic Ocean. (*Source:* U. S. Navy Hydrographic Office. Publ. No. 705, 1958; Table 1.)

To examine the distribution and persistence of the shallow temperature maximum some of the data have been grouped, rather arbitrarily, as groups lettered A–K (Fig. 5). These groupings run clockwise in the Beaufort Sea, in keeping with the circulation of the Arctic Water (Fig. 1). An attempt

has been made to include in each group data from more than one year. Fig. 5 discloses the following:

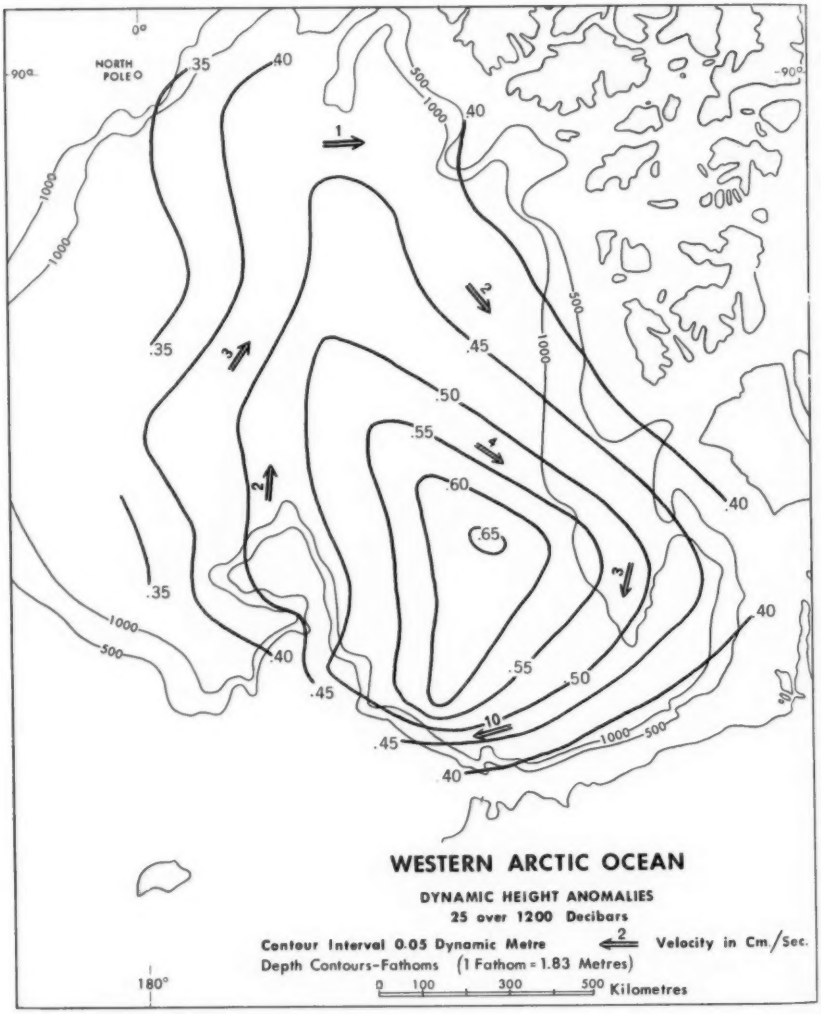



**Fig. 4.** Dynamic topography of the western Arctic Ocean.

(1) The shallow temperature maximum must be considered a persistent phenomenon because the curves are quite similar within each group even though the stations were occupied in different years and seasons.

(2) The shallow temperature maximum is best developed due north of the Chukchi Sea, and the difference between the maximum and ambient temperature decreases as the water travels around the Beaufort Sea gyral. The temperature maximum may be observed near the North Pole, as evidenced by the atypical station in G (the station in Fig. 1 located closest to the North Pole). It is present to some extent over the interior of the Beaufort Sea, and it occasionally may occur in an isolated locality north of Alaska (the atypical station in K).

(3) Below the maximum there is a temperature minimum at about 150 metres that is just as persistent as the maximum, with values from −1.4 to −1.5°C., even though the temperatures above and below are higher. Note that these temperatures are 0.2° to 0.3°C. above freezing.

It may be concluded that some continuing supply of relatively warm water is required to maintain the shallow temperature maximum. Such water either may acquire its characteristics, that is its temperature and salinity, locally or may acquire these at some distance and be advected into this part of the Arctic Ocean. The possibility of local origin is ruled out for the following reasons:

(a) The freezing of ice is the local process which would increase the density of the water to the point where it could sink to the required level. However, when this is due to freezing the temperature of the water leaving the surface is that of freezing for its salinity, whereas the water of the shallow temperature maximum is well above its freezing point.

(b) Heat might be supplied by radiation to raise the temperature above freezing, but the surface waters heated by radiation are of too low a density to sink even to 50 metres. This also rules out the possibility of the temperature maximum being formed and maintained by residual summer heat introduced in the relatively low-salinity, ice-free peripheral areas in the Arctic, e.g., north of Alaska, as suggested by Worthington (1953, 1959).

Thus, the shallow temperature maximum observed in the western Arctic Basin appears to be maintained by advection from some external source. The phenomenon is best developed in the area due north of the Chukchi Sea, and it is highly probable that the large amounts of water flowing north through Bering Strait into the Chukchi Sea contribute to some extent to the formation and maintenance of the temperature maximum. So long as it is present, then, the shallow temperature maximum would indicate the penetration of Bering Sea water into the Arctic Ocean. This view is substantiated by water-mass analysis.

Fig. 6 presents T-S diagrams in which a single observation of temperature and salinity is plotted as a point, and points of equal density show as curved lines labelled $\sigma_t$. The middle part of the diagram shows data from stations comprising groups A–D, the groups located due north

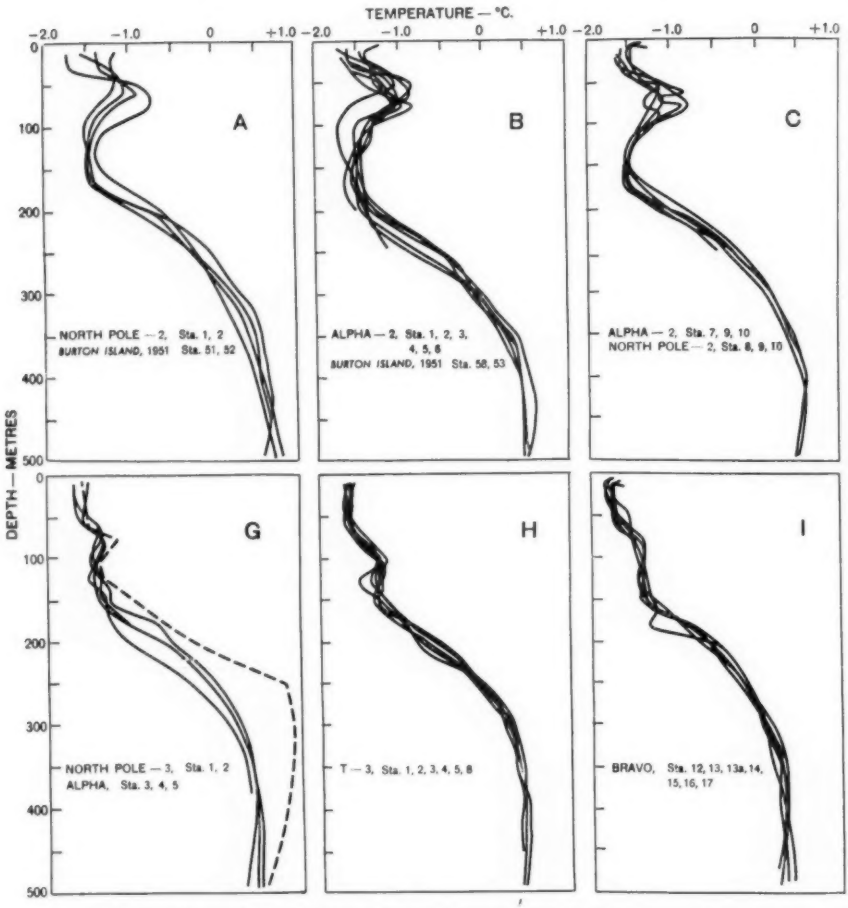
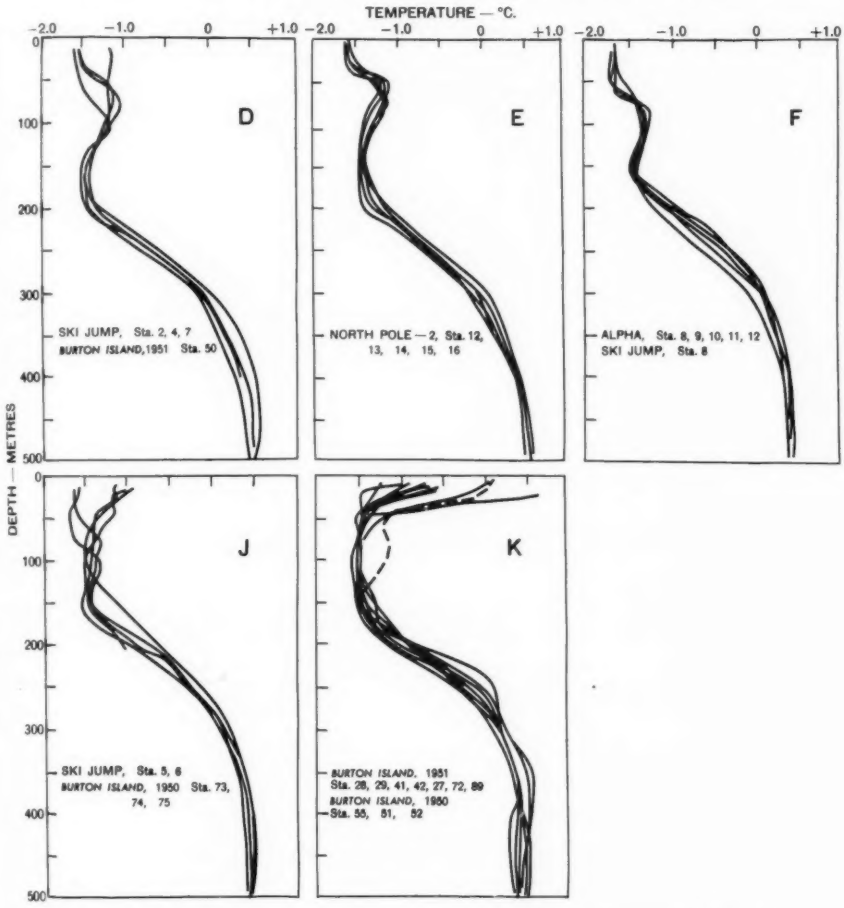



**Fig. 5.** Vertical distribution of temperature at selected groups of stations.

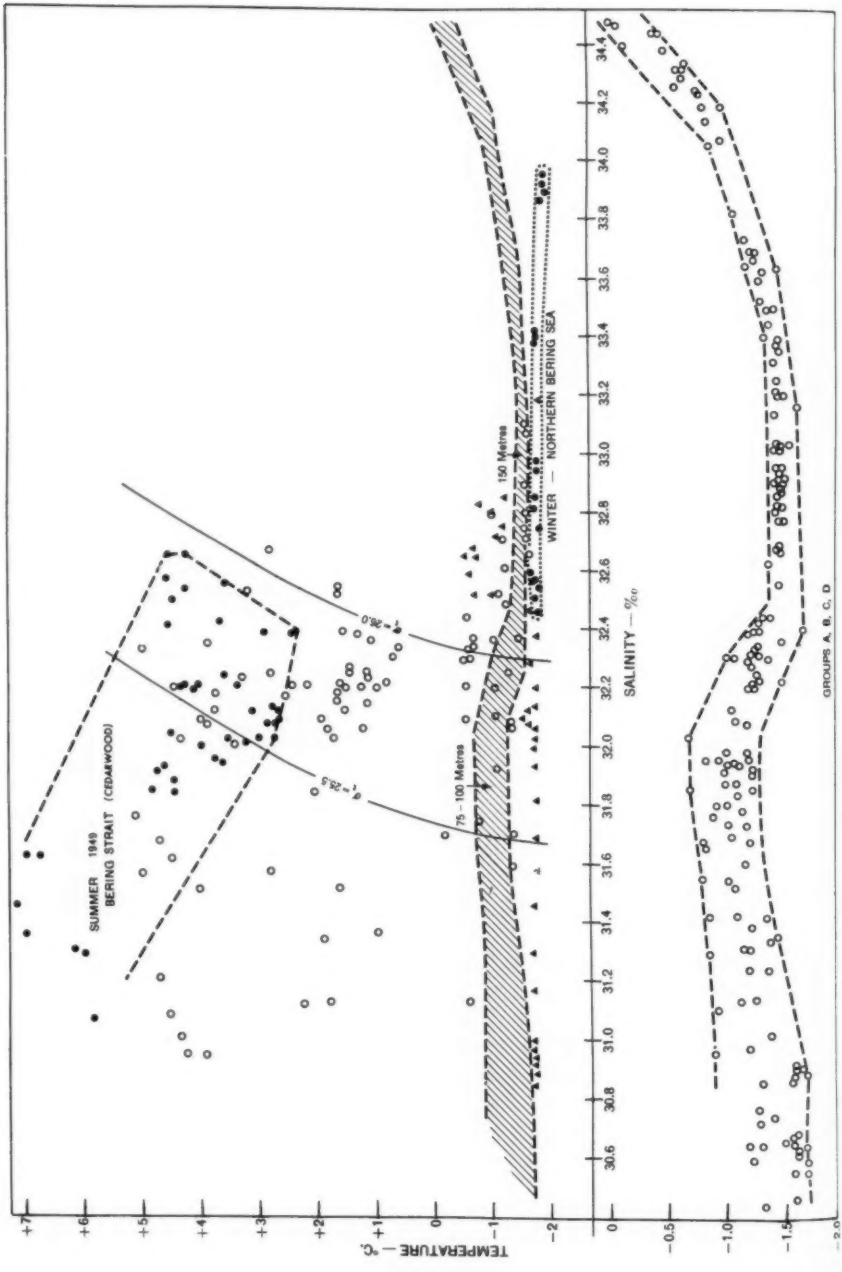
of the Chukchi Sea where the shallow temperature maximum was best developed. Note that the shallow temperature maximum appears as a "hump" in the salinity range 31.6–32.4 $^{0}/_{00}$. An envelope drawn around these values has been transferred to the upper and lower parts of the figure so that the water characteristics may be directly compared with those of the water flowing through Bering Strait and of the shelf water that occupies large parts of the Chukchi and East Siberian seas.

A number of stations are available from the western part of the Chukchi Sea from the *Maud* in 1922 (Sverdrup 1927). Individual observations are shown by triangles in Fig. 6. These data represent eastern Siberian shelf water. Even though taken in summer, the surface layers were cool because in 1922 the ice pack lay well to the south. Below the




*(See* Fig. 1 for locations of station groupings, Table 1 for sources of data.)

surface, in the level from 10 metres down to 30–60 metres, there was a fairly thick layer of intermediate shelf water with a salinity (and hence density) range the same as that of the water of the shallow temperature maximum. The temperature of this water was close to freezing, −1.5° to −1.6°C. According to Sverdrup, this intermediate water was encountered at all shelf stations and probably represented the water that during the previous winter had covered the greater part of the East Siberian and Chukchi seas. The bottom shelf water was of a different character, slightly saltier and warmer. It should be noted here that secular differences are not important in the use of *Maud* data, because we are discussing rather broad ranges of property; it is only necessary to assume that the processes involved have not changed significantly in the last 40 years.


SUMMER 1949
BERING STRAIT (CEDARWOOD)
σt = 26.0
σt = 26.5
75 - 100 Metres
150 Metres
WINTER — NORTHERN BERING SEA
TEMPERATURE — °C.
SALINITY — ‰
GROUPS A, B, C, D

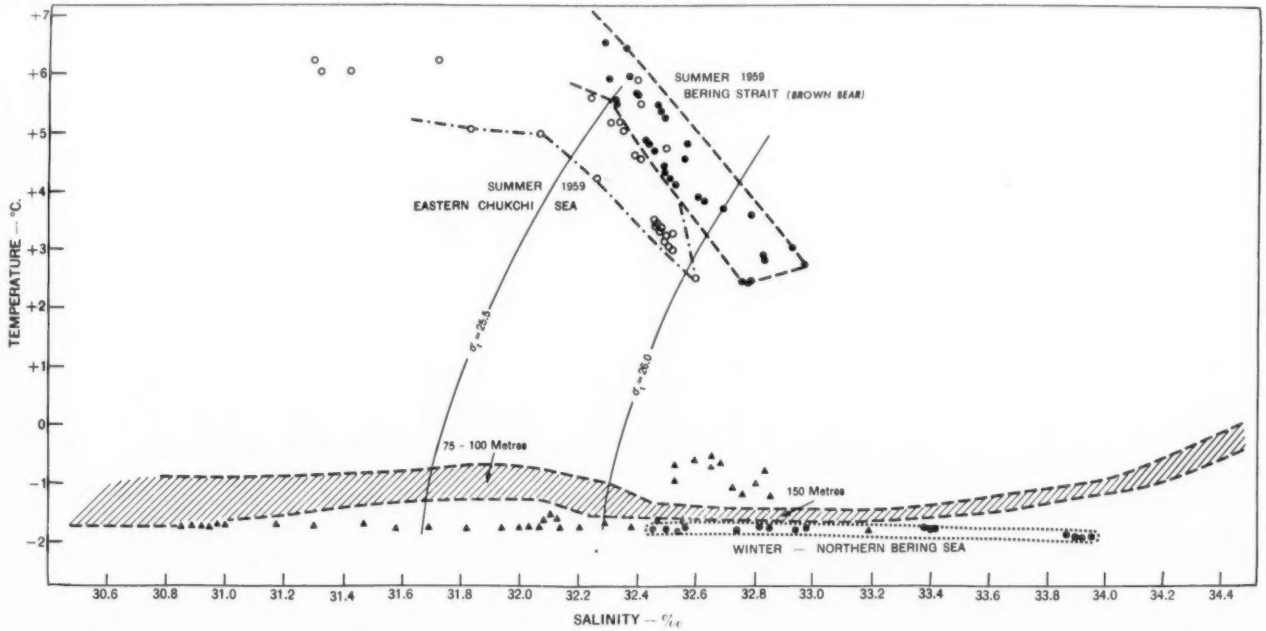



**Fig. 6.** Temperature-salinity observations from Bering Strait and eastern Chukchi Sea compared with observations from the Siberian shelf and Arctic Ocean. Upper — *Cedarwood* 1949; middle — observations from Arctic Ocean groups A — D from which the envelope in the upper and lower sections is derived; lower — *Brown Bear* 1959. Solid circles — observations from Bering Strait; open circles — observations from eastern Chukchi Sea; triangles — observations from *Maud* 1922. *(See* Table 1 for sources.)

What are the characteristics of the Bering Sea water that flows north through Bering Strait? Unfortunately, no concurrent temperature and salinity data in winter are available from Bering Strait proper, but during three icebreaker cruises in 1951 and 1955 stations were occupied just south of Bering Strait in the northern Bering Sea (U. S. Navy Hydrographic Office 1954, 1958). The data, plotted on the T-S diagrams, show that the water flowing north toward Bering Strait in winter may have a broad range of salinity (32.4–34.0 ‰) but is saltier than the water of the shallow temperature maximum. Its salinity range corresponds to that of the temperature minimum at 150 metres, and its temperature is that of freezing for its salinity.

The Bering Sea water flowing into the Chukchi Sea in summer is much warmer and also contains less salt than the winter water. Numerous data are available from a *Brown Bear* cruise in August 1959 (Fleming 1959) and a cruise of the *Cedarwood* in August 1949 (U. S. Navy Electronics Laboratory 1954). All observations made in Bering Strait during these two cruises are plotted in Fig. 6 and enclosed with a dashed line. At each station the observations were plotted from the bottom up, so that the coldest and most saline values are all included but warmer and fresher values nearer the surface may have been omitted.

The water flowing through Bering Strait in summer is considerably warmer and is somewhat less saline than in winter. It is significant that the resulting sigma-t (density) of most of this north-flowing water lies in the range 25.5–26.0, exactly the sigma-t range of the water of the shallow temperature maximum. Mixing of waters in the ocean may take place along sigma-t surfaces or across sigma-t surfaces, but on the basis of energy considerations the mixing that takes place is preferentially along surfaces of equal sigma-t (Sverdrup *et al.* 1942).

This analysis indicates that the water of the shallow temperature maximum originates as summer Bering Sea water, which, after flowing through Bering Strait, mixes in the Chukchi Sea mainly along sigma-t surfaces with the large amounts of intermediate shelf water. As further confirmation, observations made by *Brown Bear* and *Cedarwood* in the eastern Chukchi Sea considerably north of Bering Strait are also plotted in Fig. 6. As the water flowing north through Bering Strait tends to hold to the Alaskan coast, these observations lie in the path of this flow and it is apparent from the T-S diagrams that most of the mixing is taking place in the range of sigma-t 25.5–26.0.

Possibly the water of the temperature minimum at 150 metres may, in part, originate and be maintained by mixing of appropriate amounts of Bering Sea water with shelf water. In this case bottom shelf water would mix with winter Bering Sea water, and the resulting mixture would be denser and lie below the water of the shallow temperature maximum in the Arctic Ocean. The heat to maintain the water of the temperature minimum at 0.2° to 0.3°C. above freezing would be supplied by the bottom shelf water.

It is concluded that Bering Sea water continually flows north into the Chukchi Sea where it mixes with Siberian shelf water and then joins the Arctic Ocean circulation in the area northwest of Point Barrow. Estimating from the characteristics of the summer water, the water of the shallow temperature maximum is comprised of about 10–20 per cent Bering Sea water and 80–90 per cent intermediate shelf water. The consequences of the intrusion of this modified Bering Sea water on the oceanography of the Arctic Ocean may be summarized thus:

(a) The intruding Bering Sea water in the Beaufort Sea gyral effectively separates deeper Atlantic water from Arctic Ocean surface water, and also limits the depth to which local surface processes are effective in altering the properties of the water column. This separation severely limits any influence of Atlantic water on the surface water in this area, and it likewise limits the depth of local vertical convection associated with the freezing of ice. The deepest convection found as evidenced by homogeneous properties is to depths of less than 70 metres.

(b) The shallow temperature maximum is an excellent tracer of the Bering Sea water, and makes it possible to estimate the vertical eddy coefficients associated with its decay as the water travels around the Beaufort Sea gyral. For the grouped temperature profiles, the value of the temperature maximum may be considered a result of the balance of horizontal advection by vertical diffusion:

$$U\frac{\partial \theta}{\partial x} = \frac{\partial}{\partial z}\left(K_z \frac{\partial \theta}{\partial z}\right)$$

where
$U$ = average velocity
$\theta$ = temperature
$x$ = distance along the line of flow
$z$ = distance in the vertical
$K_z$ = vertical eddy coefficient

Using data from drifting-stations where the ice tends to follow the same water mass, the balance may be simply expressed by :

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_z \frac{\partial \theta}{\partial z}\right)$$

where $t$ = time. Solutions of these equations for $K_z$ lead to values of between 0.2 and 1.1 cm.$^2$ sec.$^{-1}$.

(c) The inflowing water from Bering Sea will have very little influence on ice conditions in the Arctic Basin. The winter water is at the freezing point, the same as the upper and intermediate water in the Chukchi Sea. The summer water loses its heat very rapidly through mixing with the cold intermediate shelf water, and the density of the mixture is such that it enters the Arctic Ocean at subsurface levels. Thus the influence of Bering Sea water on the ice cover will be limited to the upward flux of heat from the water of the shallow temperature maximum to the

very surface layers (upper 50 m.) where it could affect the ice. The maximum upward heat flux is estimated by using the observed vertical temperature distribution and the calculated eddy coefficient. Solution of

$$\frac{1}{A}\frac{dQ}{dt} = \rho C_p K_z \frac{d\theta}{dz}$$

where A = area, Q = heat, $\rho$ = density and $C_p$ = specific heat gives a maximum value for the heat flux upward across a 1 cm.$^2$ area at 50 metres depth of 4 x $10^{-4}$ cals. cm.$^{-2}$ sec.$^{-1}$ or about 35 cals. per cm.$^2$ per day. This calculated upward flux of heat is considerably less than the estimated heat loss from the surface in these high latitudes, which is about 330 cals. per cm.$^2$ per day gross or 108 cals. per cm.$^2$ per day net (Sverdrup *et al.* 1942, p. 99).

## References


Antonov, V. S. 1957. Klimaticheskoye rayonirovaniye vodosbornogo basseina arkticheskikh morei. Probl. Arkt. No. 2:97-105.

Arkticheskii Nauchno-issledovatel'skii institut 1946. Ekspeditsiya na samolete "SSSR-N-169" v rayon "polyusa nedostupnosti". Nauchniye resul'taty. Moskva: Glavsevmorput, pp. 116-18.

Barnes, C. A. and T. G. Thompson 1938. Physical and chemical investigations in Bering Sea and portions of the North Pacific Ocean. Univ. Wash. Publ. Oceanogr. 3:35-79.

Bloom, G. L. 1956. Current, temperature, tide, and ice growth measurements, eastern Bering Strait – Cape Prince of Wales 1953-55. U.S.N. Electron. Lab., Res. Rep. 739, 24 pp.

Collin, A. E. 1959. Canadian oceanographic activities on IGY drift station "Bravo". Fish. Res. Bd. Canada Man. Rep. Series No. 40, 35 pp.

English, T. S. Project Ice Skate, Drift Station Alpha, oceanographic data — 1958. W.H.O.I. Ref. Series (in prep.)

Farlow, J. S. 1958. Project Ice Skate oceanographic data. W.H.O.I. Ref. No. 58-28. 18 pp.

Fleming, R. H. 1959. Oceanographic survey of the Eastern Chukchi Sea, 1 August to 2 September 1959. Preliminary Report of *Brown Bear* Cruise No. 236. Univ. Wash. Dept. Oceanogr. Ref. No. 59-30, 14 pp.

Gast, J. A. 1960. Oceanographic observations in the Arctic Ocean from the drifting station Charlie. Univ. Wash. Dept. Oceanogr. Ref. No. 60-33. (unpublished manuscript.)

Gudkovich, Z. M. 1959. Ice drift in the central Arctic Basin. Preprints, Int. Ocean. Congress. Amer. Assoc. Adv. Sci., pp. 545-7.

Kusunoki, K. 1959. Oceanographic observations on Ice Island T-3 in the summer of 1959. Tech. Rep. No. 1, Inst. of Low Temp. Sci., Hokkaido Univ., Japan, 12 pp.

LaFond, E. C. 1960. Arctic oceanography by submarines. U. S. Naval Inst. Proc. 86:90-6.

Maksimov, I. V. 1945. Determining the relative volume of the annual flow of Pacific water into the Arctic Ocean through Bering Strait. Probl. Arkt. No. 2:51-8. (Transl.)

Metcalf, W. G. 1960. A note on the water movement in the Greenland-Norwegian Sea. Deep-Sea Res. 7:190-200.

Muguruma, J. 1960. Oceanographic observations on T-3, the winter 1959-60. Tech. Rep. No. 2, Inst. of Low Temp. Sci., Hokkaido Univ., Japan, 21 pp.

Nansen, F. 1902. Oceanography of the North Polar basin. Sci. Res. Norweg. N. Pol. Exped. 1893-96, Vol. III, No. 9, 427 pp.

Ratmanov, G. E. 1937. K gidrologiy Beringova i Chukotskovo morei. Leningrad. Gosudarstv. gidrolog. inst. Issled. mor. SSSR No. 25:10-174.

Shirshov, P. P. 1944. Scientific results of the drift of station North Pole. Ak. Nauk SSSR Obshcheye sobraniye. Feb. 1944, pp. 110-40. (Transl.)

Somov, M. M. 1954. *Edit.* Observational data of the scientific-research drifting station of 1950-1951. Materialy nablyudeniy nauchno-issledov. dreifuyushchei stantsii 1950/51 goda. Leningrad: "Morskoi transport". (Transl.)

Sverdrup, H. U. 1929. The waters on the North Siberian shelf. Sci. Res. Norweg. N. Pol. Exped. *Maud* (1918-25), Vol. IV, No. 2, 131 pp.

————1956. Oceanography of the Arctic. *In:* The Dynamic North, (U.S.N., Chief Nav. Oper. June 1956), Book I, Sec. V, 32 pp.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The Oceans. New York: Prentice-Hall, 1087 pp.

Timofeyev, V. T. 1957a. Atlanticheskiye vodi v arkticheskom basseine. Probl. Arkt. No. 2:41-51.

————1957b. O formirovanii donnikh vod tsentral'noi chasti arkticheskovo basseina. Probl. Arkt. No. 1:29-33.

————1958. O "vozraste" atlanticheskikh vod v arkticheskom basseine. Probl. Arkt. No. 5:27-31.

Treshnikov, A. F. 1959a. Oceanography of the Arctic Basin. Preprints, Int. Ocean. Congress, 1959. Amer. Assoc. Adv. Sci., pp. 522-3.

————1959b. Poverkhnostniye vodi v arkticheskom basseine. Probl. Arkt. No. 7:5-14.

Treshnikov, A. F., and E. I. Tolstikov. 1956. Dreifuyushchie stantsii v tsentral'noi Arktike "Severnyi polyus 3" i "Severnyi polyus 4". Moskva: Znanie, 32 pp.

U. S. Navy Electronics Laboratory 1954. Oceanographic cruise to the Bering and Chukchi Seas, summer 1949. Part IV: physical oceanographic studies, Vol. 2 data report. U.S.N. Electron. Lab., Res. Rep. 416, Vol. 2, 30 pp.

U. S. Navy Hydrographic Office 1954. Oceanographic observations, U.S.S. *Burton Island*, 1950-1953. H. O. Publ. 618-c, 309 pp.

————1958. Oceanographic survey results, Bering Sea area, winter and spring 1955. H. O. Tech. Rept. 14, 95 pp.

Worthington, L. V. 1953. Oceanographic results of project Ski Jump I and Ski Jump II in the Polar Sea, 1951-1952. Trans. Amer. Geophys. Un. 34(4):543-51.

————1959. Oceanographic observations. *In:* Scientific studies at Fletcher's Ice Island, T-3, (1952-1955). Geophys. Directorate, U.S.A.F. Camb. Res. Cent., Geophys. Res. Paper No. 63, Vol. I, pp. 31-5.

# METHODS OF DETERMINING THE NUMBERS AND AVAILABILITY OF RINGED SEALS IN THE EASTERN CANADIAN ARCTIC

**Ian A. McLaren***

## Introduction

FOLLOWING upon studies of the life history of the ringed seal, *Phoca hispida* Schreber, its bionomics are being considered in order to develop a rational basis for exploitation. A preliminary report on the economics of seal hunting has been published previously (McLaren 1958), but was not written for wide distribution. A discussion of population ecology and sustainable hunting yield, which is central to the problem of exploitation, is given by McLaren (1961). The present paper is concerned with those methods that can be used in the field without collection of specimens. The work is by no means finished, and is presented here in the hope that readers whose activities take them to the north can make observations to help test and improve the accuracy of the estimates and methods. The pertinent observations are listed at the end of the paper, and it can be seen that most are neither difficult nor time consuming.

## Census from shipboard

Most species of seals tend to congregate in geographically circumscribed areas, which facilitates direct assessment of numbers, either from the air (e.g., Surkov 1957) or from the ground (e.g., Bartholomew and Hubbs 1952). Unfortunately the ringed seal is not sociable and does not lie out on land, so that in summer population estimates must be made from counts of seals scattered in the open coastal waters. Sometimes it is possible to make complete counts of seals in some well-delimited body of water, but this is generally impractical. Large areas of water are best covered by some variant of the "strip-census" method.

Two published forms of strip census of marine mammals from ships under way have shortcomings. One method involves arbitrary estimate of the width of the census strip, within which all animals are presumed counted (Taylor *et al.* 1955), and the other attempts to include a correction for the decreasing probability that animals at greater distances will be

*Arctic Unit, Fisheries Research Board of Canada

seen (Mackintosh and Brown 1956). Neither accounts for the fact that sea mammals spend some of their time under water, where they may escape being seen from a moving ship. There is also, of course, a large literature on the strip census of terrestrial mammals and terrestrial and marine birds, but much of this is not pertinent for the same reason.

It is first necessary to determine the width of the strip, within which can be counted all or a calculable proportion of the animals actually present. The observer at sea is untroubled by many of the variables of terrain which plague the census-taker on land, but weather, sea conditions and eyesight all remain to influence the distance at which a seal can be seen. The present method is designed to standardize these influences. Firstly, since even slight ruffling of the sea surface makes visibility limited and variable, the census must be carried out in flat-calm weather, preferably when there is a bright, pearly overcast. On such days the heads of seals stand out against the uniformly light water, and visibility is almost wholly determined by the visual acuity of the observer. Secondly, the limit of visibility is determined by the observer himself at the time of the census by dropping floating objects the size of seals' heads over the stern and timing their disappearance in the ship's wake at known speeds. As a standard measure of visual acuity, black bars on a white background in bright light should be discriminated by normal eyes when the distance between the bars subtends an angle of about 30 seconds (Pirenne 1948). This suggests that a black disc, six inches in diameter, should not be visible against a white background in daylight much beyond a half mile. From determinations made under field conditions as described, it is believed that an object the size of a seal's head will only rarely be seen beyond a third of a mile.

The actual count of seals must be carried out from a ship or boat that is steadily under way; those that change speed or course frequently (as in seal hunting) are not suitable. The line of sight must be unobscured by ice or land to the limit of visibility. The observer must be diligent, but need not be experienced, as it takes no more skill to see a seal's head against a uniform background than to see a floating object used as a standard. Any aids (binoculars, assistants) can be used to help spot seals, as long as such seals can be seen by the observer himself with the naked eye. He should stand at the bow, or any place with unimpeded vision, and swing his line of sight steadily through 180° to cover all water ahead and abeam. Scanning should be sufficiently rapid so that no seals are missed when they surface briefly. The non-gregarious ringed seal is rarely common enough to cause confusion, but if the time, direction, and estimated distance are noted, an occasional "repeat" can be eliminated.

Having counted all the seals in a strip of water twice as wide as the limit of visibility, we can determine the theoretical number present as follows. (I am indebted to Dr. Joseph T. Armstrong for pointing out an error in an earlier discussion of the method and for formulating the proof given here.)

It can be seen from Fig. 1 that where r is the limit of visibility and v is the speed of the ship, then the length of time t that a point can be kept (continuously) under surveillance is:

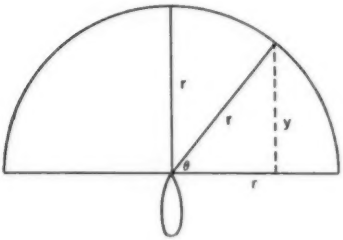



Fig. 1.

$$t = \frac{y}{v}$$

$$= \frac{r \sin\theta}{v}$$

Now assume that the average seal is under water for u minutes and on the surface between dives for s minutes, and that no point can be kept under surveillance for as long as u minutes and that no seal is counted twice in any event (see above). Then the probability (p) of seeing a seal located at a given point under surveillance may be expressed as:

$$p = \frac{t}{s+u} + \frac{s}{s+u}$$

And, where t is the length of time a point can be kept under surveillance (above):

$$p = \frac{r \sin\theta}{v(s+u)} + \frac{s}{s+u}$$

Therefore the average probability ($\bar{p}$) is expressed as:

$$\bar{p} = \frac{1}{\frac{\pi}{2} - 0} \int_0^{\frac{\pi}{2}} \left( \frac{r \sin\theta}{v(s+u)} + \frac{s}{s+u} \right) d\theta$$

$$= \frac{1}{\frac{\pi}{2} - 0} \int_0^{\frac{\pi}{2}} \frac{r \sin\theta}{v(s+u)} \, d\theta + \frac{1}{\frac{\pi}{2} - 0} \int_0^{\frac{\pi}{2}} \frac{s}{s+u} \, d\theta$$

$$\bar{p} = \frac{2r}{v(s+u)\pi} + \frac{s}{s+u} \qquad (1)$$

Now, where $N_o$ is the number of seals counted in the census strip and $N_t$ the theoretical number present, then:

$$N_t = \frac{N_o}{\bar{p}} \qquad (2)$$

Numerical example: Along the south coast of Frobisher Bay, 43 ringed seals were counted in a known area (distance travelled times twice the limit of visibility). When the ship's speed was 0.12 nautical miles per minute, the limit of visibility for the observer was determined at 0.32 miles, and the average seal was estimated to be on the surface for 1 minute and below for 3, then the theoretical number would be:

$$\bar{p} = \frac{2 \cdot 0.32}{0.12(3+1)3.14} + \frac{1}{3+1}$$

$$= 0.68$$

$$N_t = \frac{43}{0.68}$$

$$= 63 \text{ seals.}$$

There are certain assumptions underlying this method which may influence the accuracy of the estimates, and which therefore deserve brief consideration here.

First of all it may be seen that the limit of visibility, and the times spent by seals below and on the surface are all applied in the formula as averages, but these must be rather variable. Large seals will be visible farther than average seals and small ones not as far, and it can be shown that the result of this will be a slight overestimate (by a few per cent) when the approximate range of size of the ringed seal is taken into account. A variable time spent on the surface introduces a slight underestimate, which is to some extent cancelled by the effect of a variable time spent under water, when average figures are used for these times. All in all, it is believed that the bias introduced by these assumptions is not serious, and could not be eliminated without a very cumbersome formulation.

Secondly, no attempt is made to attach a variance to the estimate of seal numbers, although this will be affected by the distribution patterns of the seals. The probability that a census will be unrepresentative is smallest when the seals are *evenly* distributed, larger when they are *randomly* distributed, and largest when they are *clustered*. The ringed seal is not sociable, although individuals may group in particularly favourable areas — to feed where there is upwelling, for instance. Of course censuses may be used to detect just such concentrations, but as with any method that can be devised, the more numerous the local areas are that can be covered, the more accurate are the population estimates over wider areas.

Thirdly, we have not considered the possible effect of the presence of the ship on the behaviour of the seals. It is well known that seals, especially young ones, may be attracted by a boat. Eskimos will often stop the boat

to entice the seals closer for a rifle shot. Whether a ship steadily under way will be as attractive is questionable. It is very unlikely that seals will be able to converge into the path of a ship travelling at more than a few knots, but it might be argued that seals that are already sufficiently close to the course will be encouraged to surface prematurely when the ship passes. The problem is somewhat like the "flushing-distance" effect in censusing birds (Hayne 1949), although its formulation will have to be accommodated to the fact that seals will come to the surface ultimately whether "flushed" or not. Some insight may be gained into the possible significance of this effect from hypothetical examples. It can be shown that since seals closest to the ship are most likely to be influenced, the correction, if any, will be smallest when the distance travelled by the ship during an average seal's dive is about equal to the limit of visibility. Let us assume that all seals within 100 yards of the ship are caused to surface, that 50 per cent of those between 100 and 200 yards surface prematurely, and that no seal beyond 200 yards pays any attention. In the numerical example of the census method given earlier, this marked effect on seal behaviour would result in an overestimate of the population of only about 4 per cent. However, if the ship in that example had been travelling twice as fast (almost 15 knots), the estimate would have been about 20 per cent too high. It seems unlikely that corrections as high as these hypothetical ones would apply. A fast-moving ship is unlikely to give much time for seals to react, even if they are disturbed by its presence. The author has noted in carrying out censuses that seals that appear well ahead on the ship's track rarely reappear to be counted close at hand, and that seals are often spotted first when they are well astern, even in the ship's wake, where they would not be counted by the present census method.

The census method outlined here should give figures in absolute densities, but results to date appear to be underestimates in the light of other information. None of the assumptions analysed above would seem to be a source of important error, and most of them would result in slight overestimates at any rate. The method would probably profit most from further data on two important variables in equation (1) — the average times spent by seals under water and on the surface in different depths and conditions of water.

### Numbers of seals based on fast-ice areas

There is ample evidence (see McLaren 1961) that ringed seal populations in regions where they are not being overexploited are not limited by food or density-dependent mortality, but by conditions of the land-fast ice. The amount and quality of fast ice determine the number of suitable "sites" for the construction of birth lairs in the ice and snow. The successful rearing of pups and even pregnancy rates are conditioned by population density. Therefore a given coastline, with an annually constant

formation of fast ice, will impose an upper size limit and a stable age-distribution on the resident seal population.

Although local weather, river outflow, tides, and other factors may be effective, the most important determinant of the amount and quality of fast ice and its snow cover is the degree of coastal complexity. The most stable fast ice with the greatest snow cover is found in bays, fiords, and in island-filled regions. We might expect the number of sites suitable for birth lairs on the ice to be a function (not necessarily linear) of distance from shore. A large series of complete counts of such lairs on ice of different conditions might be the best basis for estimating the total population represented by a coastline. This is probably not possible, since the lairs are hidden and difficult to find.

In the meanwhile, another partly deductive method has been developed. The ringed seal does not as a rule lie out on pack ice. There is reason to believe that almost the entire population can be counted on the fast ice which remains at the peak of the basking season in the late spring; both the resident adults, which lie out increasingly in the waxing sun, and the immatures, which have come in from a winter spent in the open water, are present at this time. The seasonal and geographic variations in the numbers of seals basking on the ice must be considered. Counts made in Frobisher Bay best illustrate the seasonal progression, and information from other localities suggests that the time of the peak varies almost directly with latitude (see Fig. 2).

The few suitable observations available at present (from southwest Baffin Island, Frobisher Bay, Ellesmere Island) suggest that the best ice for breeding purposes will have at least 35 seals per square mile basking on it in spring. This would be equivalent to about 7 suitable sites for birth lairs, as deduced from life tables (McLaren 1961). But, as Ellis (1957) has pointed out, seal breathing holes and birth lairs are generally scattered throughout smaller and narrower bays, whereas they occur within a mile or so of shore on more open coastlines. This pattern is of course related to the suitability of fast ice for the construction of birth lairs. Also, by the time peak counts are made much of the unstable, offshore fast ice has been converted to pack ice, giving up its basking seals to the ice remaining attached to shore. For these reasons the figure of 35 seals per square mile is presumed to apply only to ice within 1 mile of shore and greater than 1 mile from the open water. Unfortunately, there are only pre-peak counts of seals from less suitable ice, but for the present two other classes of ice have been defined. Ice close to shore on open coasts or around the peripheral islands of more complex coasts — precisely, ice within 1 mile of shore *and* within 1 mile of open water — is believed to represent about 10 seals per square mile. For ice greater than 1 mile offshore, we suggest a figure of 5 per square mile. Fast ice does not generally form much beyond the outermost capes and skerries of a coast, and where it does it is probably too unstable and poorly covered with snow to be used by reproducing seals, and is usually broken off by the

time peak counts are made. For these reasons, areas outside the straight lines joining the outermost points of a coast are treated as open water. The principles of this method are illustrated in Fig. 3.

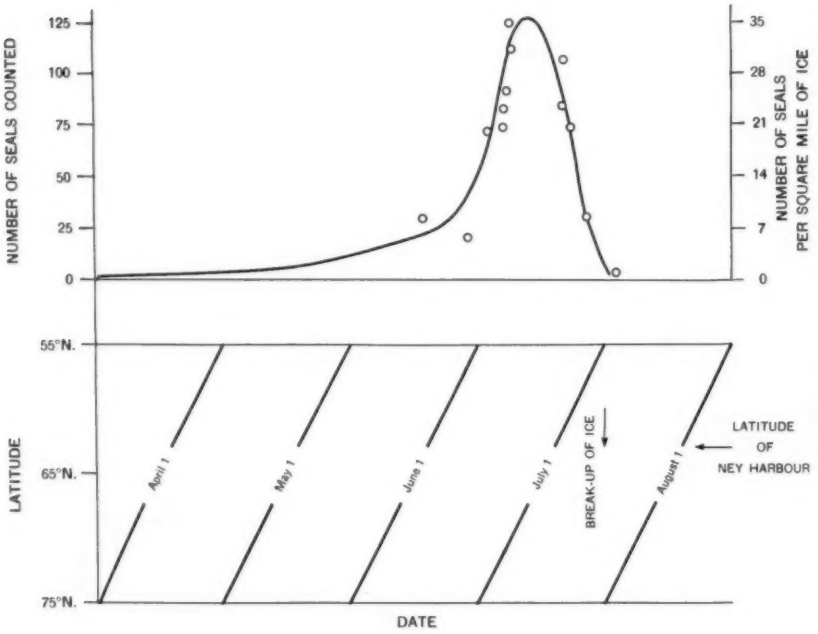



**Fig. 2.** The progression and peak of numbers of seals basking on the fast ice of Ney Harbour, Frobisher Bay, in 1957. The same form of curve is presumed to apply throughout the range of the ringed seal, and the best estimate of the effect of latitude is shown in the lower part of the graph, implying that, for example, the season is roughly a month earlier in southern Hudson Bay than in northern Baffin Island.

Using these criteria, fast-ice areas have been measured planimetrically and population estimates derived for the eastern Canadian Arctic south of Lancaster Sound. There are complications in other areas (including the totally ice-locked central Arctic), which have not yet been resolved.

It can be seen that the results are at present based on few observations. Nevertheless, the deductive element — that ice closer to shore is overwhelmingly important — probably gives the figures relative if not absolute validity. There is no doubt that the method itself will have to be made more exact and probably more complex, and this can best be done if more counts of seals on the fast ice are available from as many areas as possible.

## Availability of seals

Except very locally, the ringed seal stocks of the eastern Arctic do not appear to be over-utilized at present, and the economic problem appears to be availability of seals in most regions. The number of seals inhabiting a coast determines the sustainable yield (not dealt with in this paper), but does not necessarily reflect their availability to the hunter. Availability, for any given set of conditions and method of hunting, is directly related to seal density, which is in turn a function of both population size and the area in which the population is dispersed.

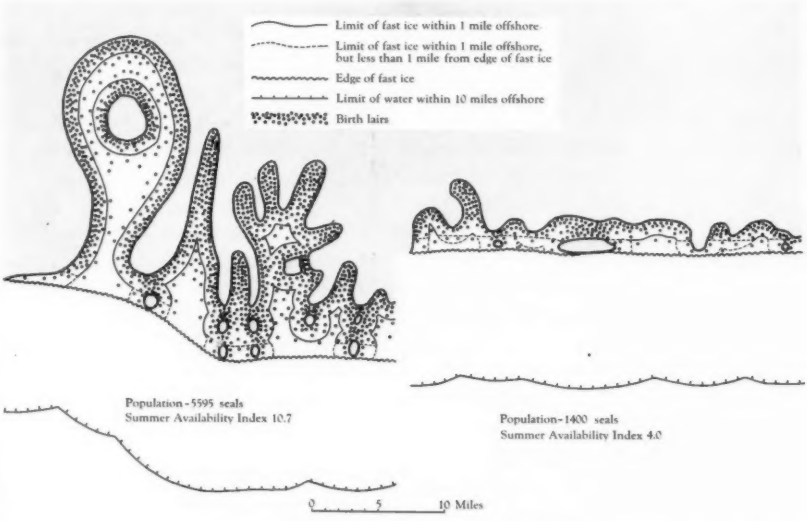

Limit of fast ice within 1 mile offshore
Limit of fast ice within 1 mile offshore, but less than 1 mile from edge of fast ice
Edge of fast ice
Limit of water within 10 miles offshore
Birth lairs
Population - 5595 seals
Summer Availability Index 10.7
Population - 1400 seals
Summer Availability Index 4.0
0
5
10 Miles

**Fig. 3.** The theoretical population of ringed seals based on the amount and quality of fast ice assumed to form on two hypothetical coastlines. The density of birth lairs on a given area of fast ice is shown in direct proportion to the number of seals presumed to be represented by that ice (about 1 birth lair per 5 seals). See text for further details.

The Eskimos do some of their hunting from boats in the open-water season. The ringed seal is essentially a coastal species, dispersing along shores but not very far offshore. If we can presume that its tendency to move offshore is the same on all coasts, then a very simple index of availability can be derived by dividing the theoretical, ice-based population size of a region by the area of water within a suitable distance of shore. This does not deny the possibility of local concentrations, as long as these bear no regular relationship to distance from shore, but is meant to apply to large sections of coast. We may examine the results of such a method by reference to Fig. 3. If we divide the populations of these

imaginary coasts by the area of water within 15 miles of shore, then the availability of seals on the complex coast relative to the simple coast is 3.0 to 1; divided by water within 10 miles of shore, it is 2.7 to 1; using the area within 5 miles of shore, it is 2.0 to 1. More information is needed on the patterns of distribution of seals in summer, but it is at present believed that a limit of offshore dispersal of about 10 miles is reasonable. The indexes of availability thus derived agree quite well with the results of shipboard censuses and information on hunting conditions.

Other seasons and circumstances may be similarly treated. The availability of immature seals hunted in the open water off the ice edge in winter should follow the summer availability quite well. There are complications in that more immature seals, which would normally move to areas of open water, tend to be trapped and forced to winter under the extensive and rapidly forming ice of complex coasts; although this effect can be formulated, it may be too cumbersome for the minor correction it introduces. From the discussion of numbers of seals it will be clear that equivalent fast ice in different regions is expected to support equivalent seal populations, so that the Eskimo who hunts at the breathing holes of seals should have comparable success throughout the ringed seal's range. Likewise the hunter who stalks seals during their short season on the spring ice should experience everywhere the same progression and peak of seal numbers, although the timing of the season will vary (see Fig. 2). Again, indexes of availability can be derived by dividing the populations of seals by the areas of ice or water in which they are dispersed. The densities of seals are sure to vary locally, but the indexes should be applicable over wide areas, and besides we can expect that the Eskimos of different regions will take similar advantage of local concentrations wherever they occur.

Although with refinement these indexes should give average densities of seals in actual numbers per square mile, they are still abstractions of availability and must be converted to catches per unit of effort. This has been done empirically using the results of day-long hunting trips carried out seriously in ideal weather in several regions of the eastern Arctic. The results indicate, for example, that a powered craft of whaleboat size hunting on the simulated complex coast of Fig. 3 might expect killing on an average 3.6 ringed seals per day, while a boat similarly engaged on the less hospitable open coast would produce only 1.4 seals. In the spring, this difference between the coasts would not be apparent to the hunter on the ice. Two weeks before the peak of the basking season, the hunter on either coast might expect to kill an average of about 2.8 seals per day, but he might expect 6.8 seals for his day's effort at the height of the basking season. At present we rely on data from 16 hunts at the ice edge in winter, 22 hunts on the spring ice, and about 75 trips in all types of boats in summer.

Though there are many other factors (including local depletion, hunting initiative) that will affect the expectations of hunters, only two modifications

seem quantitatively definable at present. The estimates of catch per unit of effort are in fact based on kill, but there is an important loss by sinking when seals are shot in the water, most serious just after the ice breaks up. Fig. 4 outlines our best present estimate of this loss in terms of the three dimensions of date (since sinking is due mainly to seasonal blubber variation), latitude (since blubber loss is related to the basking and fasting season, as outlined on Fig. 2), and seawater density (since the buoyancy of seals is directly related). Unfortunately, there are few empirical data relating sinking loss to seawater density, and this part of the graph is based on seasonal variations in amount of blubber and on considerations of specific gravities.

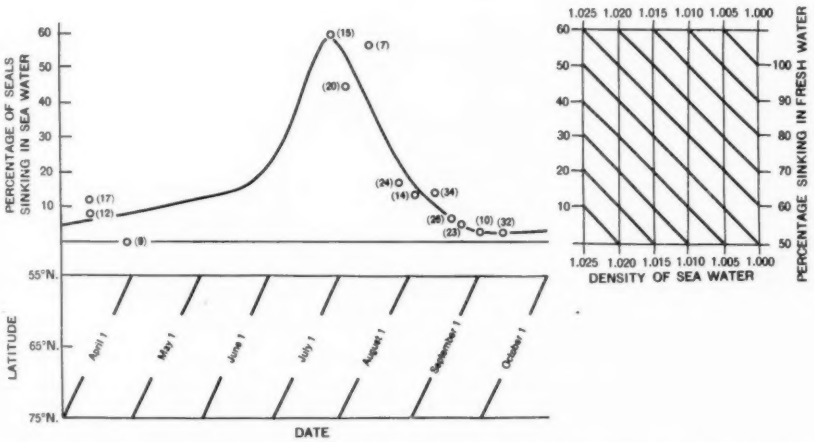



**Fig. 4.** The best present estimate of the loss of seals by sinking, in terms of date, latitude, and seawater density. Each point on the graph is the mean of dates and percentages lost of a bi-weekly sample in one of several localities of the Eastern Arctic. The shape of the curve prior to the peak was determined by consideration of the basking and fasting season, which underlies the loss of blubber and the tendency to sink.

The second major calculable modification is the weather. All our figures on catches per unit effort are based on hunting in ideal, or nearly ideal, weather. Hunting seals at their breathing holes is restricted for technical reasons to days of complete calm or very little wind, and onshore winds will generally choke the open water at the fast-ice edge with pack ice, making hunting there impossible. In spring, the numbers of seals on the ice may be affected by temperature, wind, and sunshine, although the seals tend to ignore the weather more as the season progresses towards break-up. In summer the wind is all important and makes hunting from boats unprofitable in all but the most sheltered waters. It should be possible to determine the probability of occurrence of suitable weather for a given type of hunting

for any time of year and locality. Weather records are being examined and it is hoped, for example, that isopleths of the expectations of calm and near-calm days in various seasons can be plotted for the regions concerned.

In closing, we may summarize the features of availability that have been discussed with a didactic equation, which will also pose further questions. In this equation $W_d$ is the day-by-day probability of suitable weather for a given type of hunting, $S_d$ is the proportion of seals expected to sink if killed in the water on that date, $I_d$ is the theoretical ice-based availability index for the coast, and $K_d$ is a constant, specific for each form of hunting, that will convert the availability index to kill per hunter per day. Where, as seems generally to be true, the Eskimos are not over-utilizing the stock, and when we presume that the most productive form of hunting will be pursued on a given date, then C is the potential number of seals that may be taken annually by a hunter of that region.

$$C = \sum_{d=1}^{365} W_d(1+S_d)K_dI_d \qquad (3)$$

When his annual catch is less than C, this gives a measure of unexploited economic potential, or perhaps of his initiative. This equation can also give some insight into possible means of improving such a hunting economy. Nothing, of course, can be done about $W_d$, the weather. The ringed seal, unlike some other sea mammals, can rarely be pursued into sufficiently shallow water where, if it sinks, it can be hooked from the bottom. Also, although harpoon guns have often been suggested as a means of reducing sinking loss, anyone who has hunted ringed seals knows that such weapons would be almost wholly impractical for this small species. For these reasons it appears that $S_d$ cannot be directly reduced. The availability index, $I_d$, is geographically determined, and again not subject to modification. There is only one variable in equation (3) through which C can be increased by human agency, that is $K_d$, which might be considered as a measure of the technological advantages enjoyed by the hunter.

It should also be pointed out that not all the variables apply to some forms of hunting. The best example of this is the use of seal nets. Nets, if well placed, should be unaffected by weather ($W_d$) and there should be no sinking loss ($S_d$). Although the $K_d$ of nets is very low, they should be of great value in regions where the weather is bad in summer, or where the surface salinities are low and result in excessive sinking. This was shown quite well by netting experiments in the Belcher Islands, southern Hudson Bay, in the summer of 1960 (McLaren and Mansfield 1960).

This equation can be manipulated in several other ways. For example, if utilization of the region's seal population can be extended to the level of maximum sustainable yield (which is a usual aim of subsistence economies), then improvement will lie partly in harvesting this yield with minimum waste and maximum efficiency. The time of year when C is

highest, the smallest values of $S_d$, and the least expensive means of raising $K_d$ all certainly enter into such improvement. However, much of the problem at this point is non-biological and becomes the concern of the technologist, economist, and sociologist.

### Summary of desirable field observations

Observations and ways of making them are listed here in the hope that travellers and residents in the Canadian Arctic will contribute to our understanding of the ringed seal as an important resource. Information should be sent to:

Fisheries Research Board of Canada
Arctic Unit
505 Pine Ave. West
Montreal 18, P.Q.

Readers wishing to know more about seals can obtain a guide (Mansfield 1961) as an aid to identification from this office.

1) Summer census of seals in the water. Only observations from ships or boats steadily under way at known speed on flat-calm days are suitable. The limit of visibility is determined by the census-taker by dropping floating objects the size of seals' heads over the stern and timing their disappearance in the ship's wake. The observer diligently counts all seals seen within 180° ahead and abeam. As long as he can see the seals with the naked eye, the observer may use any aids actually to spot them (assistants, binoculars). The times, positions, and estimated distances of the observed seal heads should be noted if there is danger of counting the same seal twice. (See also discussion of method in the text).

2) Times spent by seals under water and on the surface. If undisturbed seals can be observed from land or boats (preferably with power off), the times of successive dives and surfacings can be noted. The most useful information would include depth of water, even crudely as "deep fiord", "shallow bay", "well offshore", etc.

3) Counts of seals on the fast ice. Seals can readily be seen from high vantage points over wide areas of ice, especially with binoculars. Only areas which are not obscured by glare, haze, and distance should be censused. The date, place, temperature, wind, and cloudiness (the last three need be only approximate) should be noted. Since the number of seals will vary with the class of ice, the ice on which the seals are counted should be outlined on a large-scale map, or a sketch-map made. It would be helpful if at least an impression of the distribution of seals on different parts of the mapped ice could be given. Of most value would be a series of counts carried out on the same area of fast ice through the entire basking season to break-up (as in Fig. 2 of this paper). The results would be doubly valuable where the seals are undisturbed by hunting.

4) Break-up of ice. Observations on the time of break-up (departure of fast ice from the heads of bays) would complement observations of seal numbers on the ice.

5) Catches per unit of effort. Many reports on hunting conditions in the Arctic fail to distinguish between actual seal abundance and problems of weather, sociology, etc. Information is needed on the number of seals which can be killed (including those that sink) per unit time by serious hunters using various methods, during different seasons, in as many regions of the Arctic as possible. The requirements of these records are as follows: A. The hunts must be carried out in ideal weather for the form of hunting (calm or near calm for boats, in summer, sunny and not too windy or unseasonably cold for hunting on the spring ice, etc.). B. The hunters must be serious and unhampered (not hunting incidentally when travelling or when short of ammunition, for example). C. The technical nature of the hunting must be noted in the following categories (the observer may think of others or qualify these): hunting at the ice edge in winter or spring (with date); hunting on the fast ice in spring (with date, and whether on foot or with dogs); hunting at breathing holes in winter (with date); hunting from boats in the open-water season (date, type of boat, numbers of hunters per boat). D. The amount of actual hunting effort in hours or at least rough fractions of a day must be given.

6) Sinking losses. This information must be included in reports of catch per unit of effort (above). The requirements are date, region of hunting, numbers killed, and numbers lost. If at all possible some impression of the salinity of the sea water should be gained. Sometimes local geography (well offshore, at mouth of river, etc.) will give an indication of salinity, but tightly sealed surface samples are best of all and will be analysed by this office.

7) Weather records. All available records from arctic and subarctic weather stations are being examined, but pertinent observations from other coastal regions would be welcome. Formal synoptic data will be analysed, but the easiest and most valuable observations would be on the occurrence of periods of calm or light variable winds (Beaufort Scale 0-1) for durations of at least half a day. Such days can be noted at sea when the surface is oily-smooth or only ruffled in patches.

## Acknowledgements

Many individuals and organizations have assisted in the studies underlying this report. Especially valuable observations and collections have been made by Drs. M. J. Dunbar, D. V. Ellis, E. H. Grainger, H. Hildebrand, A. W. Mansfield, and P. Montreuil. I would also like to thank Drs. J. T. Armstrong, W. E. Ricker, D. E. Sergeant, and Mr. S. Apollonio for reading the manuscript and suggesting improvements.

## References

Bartholomew, G. A., Jr., and C. L. Hubbs, 1952. Winter populations of pinnipeds about Guadalupe, San Benito, and Cedros Islands, Baja California. J. Mammal. 33:160-71.

Ellis, D. V. 1957. Some observations on mammals in the area between Coppermine and Pond Inlet, N.W.T., during 1954 and 1955. Can. Field Nat. 71:1-5.

Hayne, D. W. 1949. An examination of the strip census method for estimating animal populations. J. Wildl. Mgmt. 13: 145-57.

Mackintosh, N. A. and S. G. Brown, 1956. Preliminary estimates of the southern populations of the larger baleen whales. Norsk Hvalfangst-Tidende 45:469-80.

Mansfield, A. W. 1961. Seals of arctic and eastern Canada. Fish. Res. Bd. Can., Arctic Unit Circ. in press.

McLaren, I. A. 1958. The economics of seals in the eastern Canadian Arctic. Fish. Res. Bd. Can., Arctic Unit Circ. 1, 94 pp.

————1961. Population dynamics and exploitation of seals in the eastern Canadian Arctic. *In.* The exploitation of natural animal populations, *ed.* E. D. Le Cren and M. W. Holdgate. Blackwell Sci. Publ., Oxford.

McLaren, I. A. and A. W. Mansfield. 1960. The netting of sea mammals. A report on the Belcher Islands experiments, 1960. Fish. Res. Bd. Can., Arctic Unit Circ. 6, 11 pp.

Pirenne, M. H. 1948. Vision and the eye. Chapman and Hall, London, 187 pp.

Surkov, S. S. 1957. Distribution and stocks of harp seals in the White Sea. PINRO, Murmansk, 60 pp. (In Russian).

Taylor, F. H. C., M. Fujinaga, and Ford Wilke, 1955. Distribution and food habits of the fur seals of the North Pacific Ocean. U.S. Dept. Int. Fish. Wildl. Serv., Washington, 86 pp.

# RECENT RECESSION AND THINNING OF OKPILAK GLACIER, NORTHEASTERN ALASKA*

**Edward G. Sable†**

## Introduction

The presence and general extent of a very recent glacial advance in northern Alaska have been known for several years, although little information on the time or duration of this advance has been obtained. The writer, doing bedrock mapping in northeastern Alaska in 1957-1958, was fortunate in being able to examine briefly perhaps the only locality in northern Alaska where observations and photographs of a moderate-sized subpolar glacier had been taken as long as half a century ago. This valley glacier, the Okpilak Glacier, lies in the Romanzof Mountains, northeastern Brooks Range.

The Romanzof Mountains, the highest mountain group in the Brooks Range, contain the most extensive system of valley glaciers in northern Alaska. About 600 square miles in area, the highest parts of the mountains lie between the Hulahula and Jago rivers. The central part of the mountains is deeply cut by the Okpilak River and its tributaries (Fig. 1). Altitudes of the higher peaks are about 9000 feet, and relief is as much as 7000 feet. Numerous valley glaciers as much as 5.5 miles long are estimated to cover collectively about 100 square miles; most of these are on the north side of the divide and flow in northerly directions. One of the largest is the Okpilak Glacier, which feeds the west fork of the Okpilak River. Comparisons between observations made in 1907 and 1958 show that at least the lower part of this glacier has wasted appreciably, and suggest that its latest advance may have taken place in recent historic time.

## Investigations and sources

The first geological reconnaissance along the Okpilak River valley was made by Ernest de K. Leffingwell, who ascended to within 3.5 miles of the head of Okpilak Glacier in June 1907. His report includes a general description and several photographs of the glacier (Leffingwell 1919, p. 156-157, Pl. XVIII, XIX, XX). In addition, several unpublished photographs taken by Leffingwell in this vicinity were obtained by the writer from the U. S. Geological Survey.

* Publication authorized by the Director of the U. S. Geological Survey.

† U. S. Geological Survey, Elizabethtown, Kentucky.

Field investigations by the writer in the Romanzof Mountains during the summers of 1957 and 1958 included one day spent in the vicinity of Okpilak Glacier. Photographs and observations on August 21, 1958 include some taken at or near Leffingwell's points of observation.

Aerial photography covering the vicinity of Okpilak Glacier includes Trimetrogon photographs taken at about 12,000 feet by the U. S. Air Force on July 16, 1947; low-altitude photographs taken by the U. S. Navy on August 20 and 27, 1950; and twin low-oblique transverse photographs at a scale of approximately 1:63,360 taken for the U. S. Geological Survey on August 7 and September 5, 1956. An unpublished topographic map at a scale of 1:63,360 prepared by the U. S. Geological Survey was also used in making measurements not obtained during field work. Other work on Pleistocene and Recent glaciation in the Romanzof Mountains has been done by Kunkle (1958) and Keeler (1959).

The writer's field work in 1957-8 was supported by the Arctic Institute of North America under contract with the Office of Naval Research, and by the U. S. Geological Survey. The studies were primarily of bedrock geology, and detailed observations of glacial phenomena and other surficial features were therefore not made. Although the observations given in this report are qualitatively valid, the measurements and estimates are not precise figures; the more critical ones, however, are given with probable limits of error. It is hoped that the information presented herein may help motivate interest in detailed quantitative studies of this and other glacial problems in the Romanzof Mountains.

Thanks are expressed to Dr. Richard G. Ray, U. S. Geological Survey, who rechecked altitude measurements made on the 1956 aerial photographs, and to Prof. Donald F. Eschman, University of Michigan, who critically read the manuscript.

## Okpilak Glacier

Leffingwell's (1919, p. 156-157) description of the Okpilak Glacier was limited to about the lower 2 miles. To this can now be added data obtained from more recent maps, field observations, and aerial photographs, a pair of which is shown in Fig. 2. The glacier is about 5.4 miles long, of which the main ice tongue, 2500 feet in average width, makes up the lower 3 miles. The total area covered by ice is about 5 square miles. The glacier heads at 7400 feet altitude in two composite cirques whose snow and firn areas each cover about 1 square mile. The firn limit lies at about 6400 $\pm$ 100 feet altitude, and the terminus at about 4500 feet. The ice surface has an average slope of about 6 degrees and the slope of the lower 1.2 miles is about 5 degrees. The entire glacier appears to lie within an outcrop belt of the pre-Mississippian Neruokpuk formation, composed mostly of schistose quartzite, slate, schist, and minor limestone.

Main areas of transverse crevassing occur below the cirques and 1.3 and 2.2 miles above the terminus, where the glacier surface steepens in

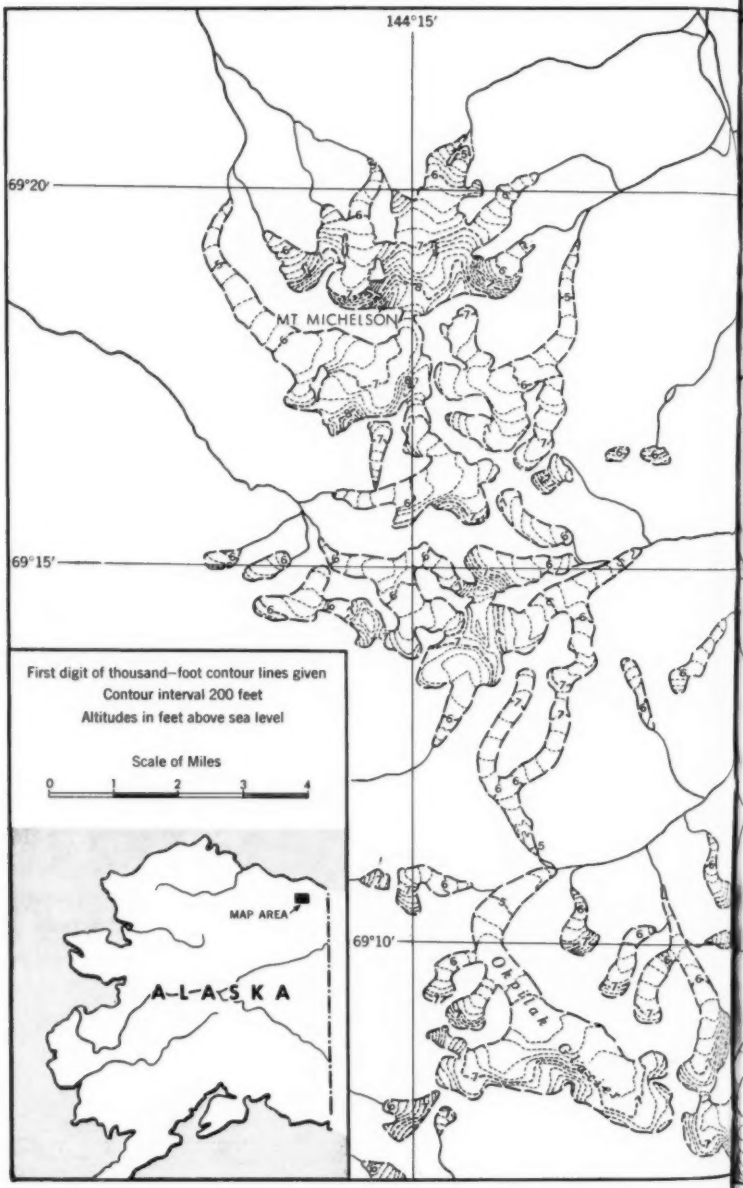
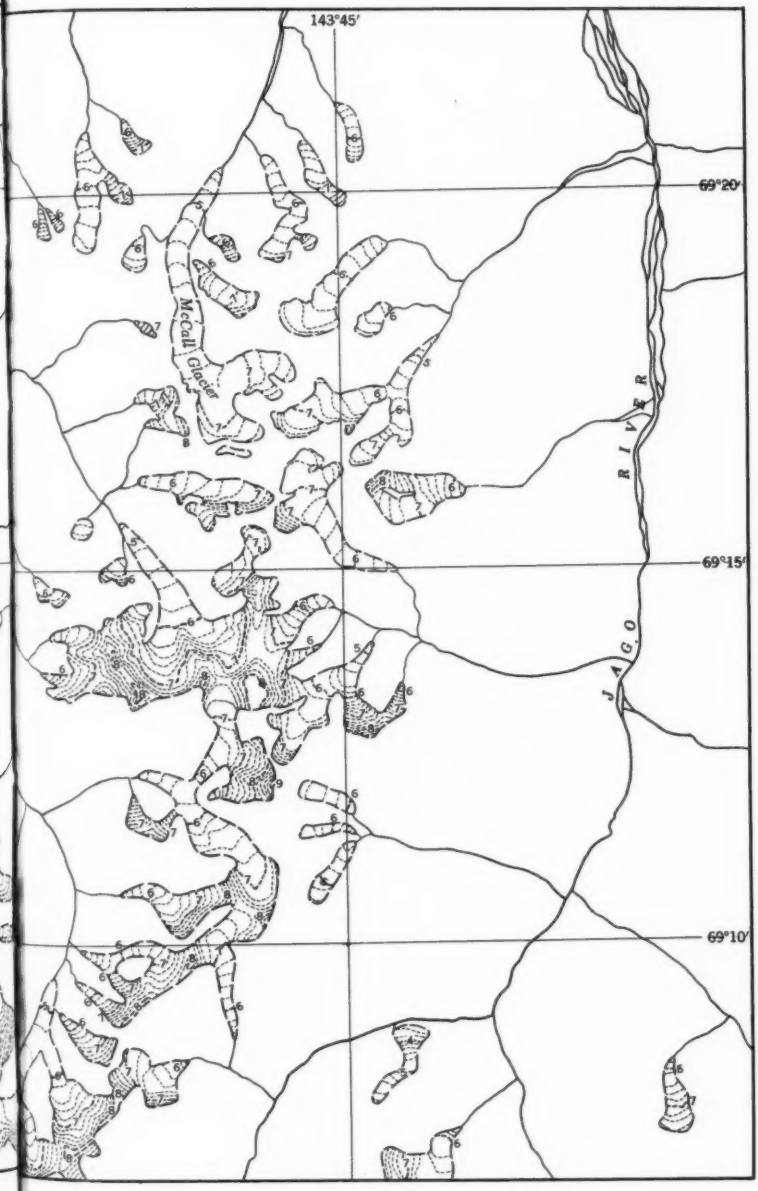



**Fig. 1.** Map showing distribution of present glaciers in n entral




iers in n entral parts of Romanzof Mountains, northeastern Alaska.

Fig. 2. Aerial photograph stereopair of Okpilak Glacier and vicinity. (Taken for U. S. Geol. Surv. September 5, 1956).

step-like form. The crevassed area 1.3 miles above the terminus was of the order of an ice fall in 1958. Smaller marginal crevasses are common. The transverse crevasses were observed by Leffingwell in 1907, but have probably become more prominent since that time because of thinning of the glacier.

Two small tributary glaciers flow into the Okpilak Glacier from the west, and there are two hanging glaciers on that side. A hanging glacier occurs also on the east side just below the terminus of Okpilak Glacier. Two well-defined medial moraines extend from the junctions of the tributary glaciers, and others, less prominent, persist northward from their sources in the cirques almost to the terminus.

The lower part of the Okpilak Glacier was free of snow in August 1958. The terminus margin was largely covered by drift, but the cover appeared to be thinner and more patchy than in 1907. Lateral and terminal moraines were described by Leffingwell to be in contact with and merging into the glacier surface. His 1907 photograph (Fig. 3A) shows at least 3 small abandoned moraines in the area between the terminus and a point about 2000 feet downstream, and his general description implies that they were fresh in appearance, consisting mostly of ice thinly veneered with drift. Except for their position in respect to the terminus and minor modifications resulting from drainage changes and wasting of the glacier, the fresh appearance of these moraines seems to have changed little in 51 years. In 1958 they were a mixture of materials ranging from clay to boulder-sized rubble without visible ice but with a hummocky surface and unstable slopes. Their maximum relief was estimated to be 75 feet.

**Evidence for recent recession.** Comparison of field photographs from 1907 and 1958 augmented by the study of aerial photographs and topographic maps show that the terminus of Okpilak Glacier has receded $1000 \pm 100$ feet in 51 years.

Leffingwell's 1907 photograph (Fig. 3A) and description of the terminus of Okpilak Glacier shows the ice to be in contact with and grading into the innermost of the abandoned recessional moraines. In 1958 the recessional moraines appeared to be little changed, but a nearly flat alluvium-covered area about 1000 feet long and 700 feet wide occupied the 1907 position of the terminal ice (Fig. 3B). A braided stream fed by meltwater flowed mostly from underneath the terminus of the glacier and crossed the flat. A small aufeis field of about 1800 square feet adjoined the northeast side of the terminus.

The mean rate of terminus recession between 1907 and 1958 is of the order of 20 feet per year. The lack of morainal material on the flat may indicate that the glacier has receded continuously during this time. No measurements on the rate of flow have been made on the Okpilak Glacier, but the rate of surface flow on the McCall Glacier, 10 miles to the northeast, was of the order of 20 mm. per day from June to November 1957 (Sater

Fig. 2. Aerial photograph stereopair of Okpilak Glacier and vicinity. (Taken for U. S. Geol. Surv. September 5, 1956).

**Fig. 3A.** Terminus of Okpilak Glacier, June, 1907. (Looking southeast; U. S. Geol. Surv. photograph by E. de K. Leffingwell).

**Fig. 4A.** Lower part of Okpilak Glacier, June 1907. (Looking south; U. S. Geol. Surv. photograph by E. de K. Leffingwell).

**Fig. 3B.** Terminus of Okpilak Glacier, August 21, 1958. Recessional moraines shown in Fig. 3A are beyond left margin of Fig. 3B.

**Fig. 4B.** Lower part of Okpilak Glacier, August 21, 1958.

1959, p. 86). If this figure is applied to the Okpilak Glacier, the mean rate of actual terminal melting rises to some 40 feet per year.

Evidence that a higher rate of recession has occurred recently is based on the comparison of aerial photographs taken in 1950 and 1956. Although the nature of the 1950 oblique photographs does not permit accurate quantitative comparison with the 1956 photographs, the change in position of the glacier terminus is noticeable, and the amount of recession between these dates is estimated at about 300 feet.

**Fig. 5A.** West fork of Okpilak River, June 1907. Lower end of Okpilak Glacier above recessional moraines of Fan Mountain glaciation in distance. (Looking southwest, U. S. Geol. Surv. photograph by E. de K. Leffingwell).

**Evidence for recent thinning.** Lowering of the ice surface in the lower part of Okpilak Glacier is evidenced by the relative positions of 1907 lateral moraines (Fig. 4A) and trim lines with respect to the 1958 ice surface (Fig. 4B). The eastern lateral moraines in 1907 were either level with or not more than 20 feet above the ice surface. Leffingwell (1919, p. 156) states that "the sides [of the glacier] as a rule grade into the lateral moraines or rest against the mountain sides. . . ."

According to field estimates and measurements on aerial photographs along selected cross-sections in the lower 1.2 miles of the glacier, the crests of the lateral moraines in 1956-8 were 150 $\pm$ 20 to 210 $\pm$ 20 feet above the edges of the glacier, and roughly from 20 to 120 feet above the higher medial ice.

In Leffingwell's photograph (Fig. 5A) the terminal ice appears to be higher than the adjoining recessional moraines. In the 1958 photograph

(Fig. 5B) taken from nearly the same location, the terminal ice is not visible, and field observations confirmed that the ice snout had melted to a gentle slope in accord with the general gradient of the glacier surface.

Most of the thinning has taken place in the lower one-third of the glacier, below the area of extensive crevassing, although thinning has also occurred above this area at least as far as the confluence of the two main

**Fig. 5B.** West fork of Okpilak River, August 21, 1958. Note thinning of Okpilak Glacier and recession of small hanging glacier at left shown by comparing with Fig. 5A.

cirques. The average amount of thinning in the lower 1.2 miles is estimated to be 150 feet, and the mean rate from 1907 to 1958 to be about 3 feet per year. As has been noted by many investigators of shrinking glaciers that terminate on land, the volume of ice lost due to thinning far exceeds the loss due to recession of the terminus. For the Okpilak Glacier, the ratio is roughly estimated to be at least 25:1.

### Tributary and hanging glaciers

All the smaller glaciers in the vicinity of Okpilak Glacier, for which photographic information from 1907 and 1958 can be compared, show evidence of marked recent recession and thinning. The terminus of the small hanging glacier shown in Figs. 3A and 5A, which was about 60 feet from

Okpilak Glacier in 1907, has retreated more than 300 feet (Figs. 3B and 5B). The tributary and hanging glaciers on the west side of Okpilak Glacier also show shrinkage effects by a diminution in width and thickness. Small hanging glaciers downstream from Okpilak Glacier have receded as much as several hundred feet.

## Correlation and conclusions

Evidence for six Pleistocene and Recent ice advances along the Jago and Okpilak rivers has been discussed by Kunkle (1958), and five glacial advances along the McCall Creek valley, 10 miles northeast of Okpilak Glacier, have been recognized by Keeler (1959). These authors tentatively correlate the advances in the Romanzof Mountains with past glaciations on the Arctic Slope 60 to 270 miles to the west and southwest (Detterman 1953), (Detterman, Bowsher, and Dutro 1958). The most recent advance is the Fan Mountain glaciation (Detterman *et al.* 1958, p. 57), whose deposits are differentiated from older, more extensive ones largely on the basis of their fresh unweathered character and their proximity to present glaciers or recently evacuated cirques. Kunkle (1958) and Keeler (1959) use the above criteria, among others, as evidence for the most recent advance in their respective areas, and correlate it with the Fan Mountain glaciation. All writers concur that the Fan Mountain deposits are difficult to differentiate from those that are at present being formed, and that the advance was probably extremely recent and short-lived.

The recessional and end moraines within 1000 to 3000 feet from the 1958 terminus of Okpilak Glacier are considered to be deposits of the Fan Mountain advance. In 1958 all this material appeared to be free of vegetation, unweathered, and to have unstable slopes. The outermost end moraine is interpreted to represent the oldest Fan Mountain moraine of the Okpilak Glacier. The absolute age of these pre-1907 moraines is unknown, and although Leffingwell's observations imply that shrinkage of the Okpilak Glacier had already taken place before 1907, he was uncertain as to whether a readvance or retreat was occurring in that year. Although the post-1907 shrinkage does not date the onset of Fan Mountain glaciation, the fresh surface appearance of the Fan Mountain moraines seems to be little, if at all, different from currently forming morainal deposits. The writer feels that it is quite possible that the Fan Mountain advance of the Okpilak Glacier occurred in recent historic time.

All glaciers observed in the Romanzof Mountains that are comparable in size to the Okpilak Glacier show evidences of recent retreat and thinning similar to those described above. Present termini of glaciers have commonly withdrawn several hundred feet leaving unweathered, unstable terminal moraines, till ridges, or formless drift at many localities. The writer believes that the shrinkage of these glaciers coincided with that of the Okpilak Glacier. It seems likely that climatic conditions leading to a general shrinkage of valley glaciers in the Romanzof Mountains and perhaps in the entire

Brooks Range have occurred during the last half of the 19th and the first half of the 20th century.

Other workers in the Brooks Range (Holmes and Lewis 1960), in northern Ellesmere Island (Hattersley-Smith 1960), and in northeast Greenland (Krinsley 1960) recognize recent advance and recent or present recession in their respective areas.

## References

Detterman, R. L. 1953. *in* Péwé *et al.* Multiple glaciation in Alaska. U. S. Geol. Surv. Circ. 289, pp. 11-12.

Detterman, R. L., A. L. Bowsher, and J. T. Dutro, Jr. 1958. Glaciation on the Arctic Slope of the Brooks Range, northern Alaska. Arctic 11:43-61.

Hattersley-Smith, G. 1960. Some glaciological studies in the Lake Hazen Region of northern Ellesmere Island. Abstr. *in* Program, First International Symposium on Arctic Geology. Reprinted from Can. Oil Gas Ind., December 1959.

Holmes, G. W., and C. R. Lewis. 1960. Glacial geology of the Mt. Chamberlain area, Brooks Range, Alaska. Abstr. *in* Program, First International Symposium on Arctic Geology. Reprinted from Can. Oil Gas Ind., December 1959.

Keeler, C. M. 1959. Notes on the geology of the McCall Valley area. Arctic 12:87-97.

Krinsley, D. B. 1960. Late Pleistocene glaciation in northeast Greenland. Abstr. *in* Program, First International Symposium on Arctic Geology. Reprinted from Can. Oil Gas Ind., December 1959.

Kunkle, G. R. 1958. Multiple glaciation in the Jago River area, northeastern Alaska. Univ. of Michigan Master's thesis, pp. 1-41, unpubl.

Leffingwell, E. de K. 1919. The geology of the Canning River region, Alaska. U. S. Geol. Surv. Prof. Pap. 109:1-251.

Sater, J. E. 1959. Glacier studies of the McCall Glacier, Alaska. Arctic 12:82-6.

# THE ALBEDO OF SEA-ICE AND ICE ISLANDS IN THE ARCTIC OCEAN BASIN

**Kirby J. Hanson**

## Introduction

THE surface albedo* and its change during the spring, summer and autumn seasons is probably the most significant regional factor affecting the heat budget of the Arctic Ocean basin. In the spring, when most of the sea-ice is covered with snow, the albedo of the surface is between 80 and 90 per cent. In mid-summer, however, the snow cover melts, fairly large puddles begin to appear on the sea-ice and the albedo becomes smaller. In addition the total ice cover is reduced from nearly 10-tenths in the spring to about 8-tenths in the summer, which lowers the albedo still further.

For studies of the surface and atmospheric heat budget of the Arctic Ocean basin, it is important to determine representative albedo values for various characteristic surfaces. The work reported here is one of the first attempts to determine the albedo of various ice conditions in the Arctic by aircraft.

## Albedo determination

### Airborne albedo measurements

During the summer of 1958, the Applied Oceanography Branch of the U. S. Navy Hydrographic Office obtained airborne radiation measurements over parts of the Beaufort and Chukchi seas. Flights were made by Patrol Squadron 9 in P2V aircraft based at Eielson AFB, Alaska; generally, they were flown along three predetermined tracks extending to 77° N. or about 300 nautical miles north of the Alaskan coast. In addition to the solar radiation measurements, photographic and visual ice-reconnaissance observations were made during the flights. Flight altitudes ranged from 200 to 2,000 feet and about one-half of the observations were made at an altitude of 500 feet. It is assumed that the effect of atmospheric scattering is negligible (Robinson 1958) and no altitude corrections have been applied to the values.

The airborne radiation measurements were made with two Eppley 50-junction horizontal-incidence pyranometers with a Leeds and Northrup Speedomax-H recording potentiometer. One pyranometer was mounted

*Ratio of the amount of total solar radiation reflected by a surface to the amount incident upon it, expressed in per cent.

facing downwards in the after-hatch of the P2V with its sensing element at the same level as the lower surface of the aircraft. Periodic checks by an observer showed that no engine oil or other film reached the glass envelope of the pyranometer. The other pyranometer was mounted facing upwards inside the navigator's astrodome, on a solid mount without provision for levelling the instrument. This created two sources of error: (a), the absorption of solar radiation by the plexiglass astrodome and (b), the lack of correct levelling of the instrument — a factor that is extremely important in polar regions (Fritz 1958). To resolve the first difficulty a transmission factor was determined using a spectral transmittance curve of the plexiglass and a spectral-energy-distribution curve for solar radiation. The transmission factor was used to correct observations obtained beneath the plexiglass astrodome. The problem of instrument levelling was resolved by accepting only those observations made when the sky was cloudy above the aircraft, thereby using only observations in which the incident solar radiation was diffuse. The results of this study are therefore not applicable to clear-sky conditions in the Arctic. With clear skies, specular reflection from the ice and water surface tends to increase the albedo slightly.

**Table 1.** Summary of airborne albedo measurements obtained over the Arctic Ocean north of the Alaskan coast during July and August 1958.

| *Surface ice cover* | *Albedo — per cent* |
|---|---|
| Open water | 4 |
| 0.1 – 0.4 | 15 |
| 0.5 – 0.7 | 22 |
| 0.8 – 0.9 | 40 |

For the period July 14-August 20, 1958, 150 albedo observations were evaluated. The albedo values were tabulated together with corresponding ice-cover observations from U. S. Navy Hydrographic Office 10-day mean ice-cover charts (USNHO TR66). The albedo observations were grouped by ice-cover classes and average albedo values were computed for the classes. The results are shown in Table 1. The average albedo of ice-free water was 4 per cent (based on 55 observations) with a standard deviation of 2 per cent. For the 8- to 9-tenths ice-cover class, the average albedo was 40 per cent (56 observations) with a standard deviation of 13 per cent. The large standard deviation results from a difference in resolution of these two variables. The Eppley pyranometer responds to about 99 per cent of the incident radiation in one-half minute (Dogniaux 1955). As the aircraft traveled about 4 miles per minute, the pyranometer saw vertically each minute an integrated area less than 2 miles in length. Neither daily nor 10-day mean ice-cover charts can provide a resolution of this magnitude.

**Surface albedo measurements**

The entire Arctic Ocean basin undergoes a large seasonal change of albedo, with minimum albedo values during the melt period. The reason for this coincidence of minimum albedo and summer melt is that large amounts of melt water collect on the relatively flat floes and effectively reduce the albedo.

**Table 2.** Albedo measurements on ice island T-3, July-October 1957.

| *Date* | *Albedo of* | | |
|---|---|---|---|
| | *snow per cent* | *melting ice per cent* | *melt-water pools per cent* |
| July 17 | — | 78 | 39 (1-2 ft. deep) |
| August 1 | — | 76 | 38 (1-2 ft. deep) |
| September 17 | 81 | — | — |
| October 8 | 78 | — | — |

To determine the albedo of natural polar surfaces, Murray (pers. com.) obtained measurements on Ice Island T-3 during 1957 (Table 2). His values for the melt period of July and August 1957 indicate that the albedo of melt-water pools (1-2 feet deep) is one-half that of the ice ridges between the pools. In order to get representative albedo values, he used portable measuring equipment a number of miles from camp, well away from camp contamination. Measurements over camp-contaminated ice in July 1958 gave albedo values of only 42 per cent and during the following year measurements again indicated an albedo of 42 per cent during July and 49 per cent during August — values that are only about one-half those obtained by Murray. With other things being equal, the lower albedos would cause about twice the amount of melting in the camp area as compared with the remainder of T-3 as has been actually shown by observations during the past few years (Smith, pers. com.)

The surface of T-3, as seen in Fig. 1, consists of quasi-parallel ridges and troughs; during the summer melt water forms elongated lakes in these troughs. Concerning the origin of these surface features, Hattersley-Smith (1957) says that wind action is the most likely cause of the rolls (ridge and trough systems) on the Ellesmere Ice Shelf as wind-driven water is an effective means of ablating ice. Crary (1960) has suggested that a lower albedo over these lakes, together with wind action to aid convection, accounts for differential surface ablation that in turn creates the ridge and trough systems. As the maximum depth of these T-3 lakes is about 4-5 feet (Crary 1960), Murray's albedo values suggest that about twice as much solar energy is absorbed by the lake bottoms than by the ice ridges between

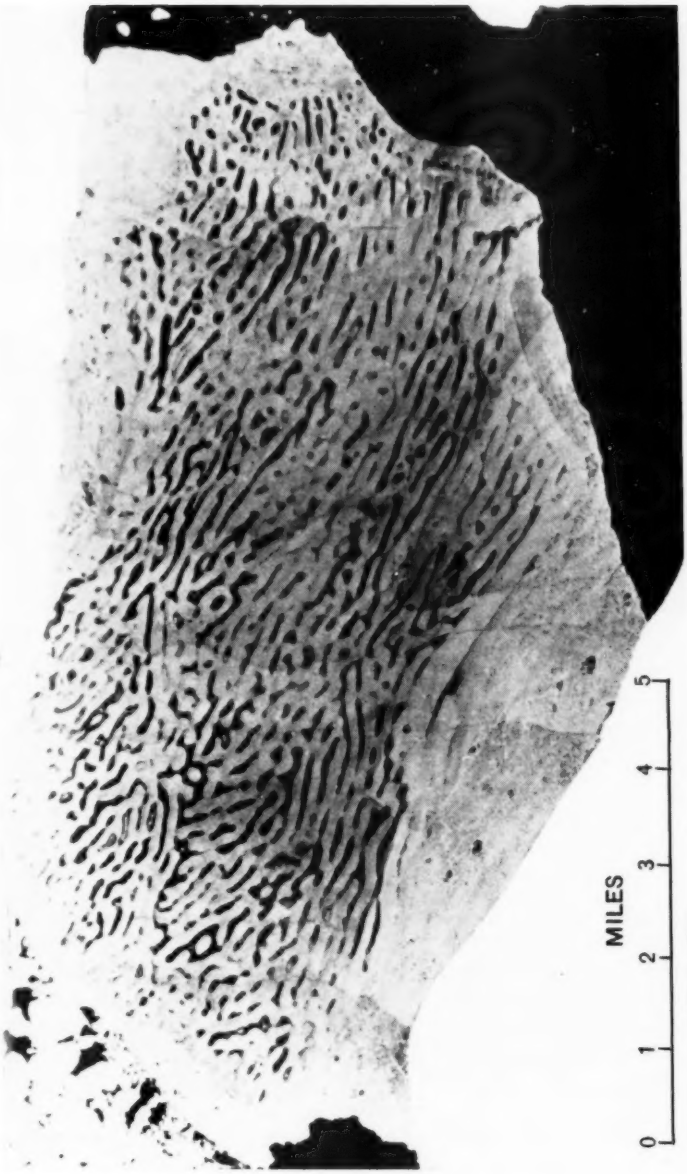



Fig. 1. Photo mosaic of ice island T-3 from Crary (1958), by courtesy of U. S. Air Force.

the lakes; this would cause twice the amount of ablation under the melt-water lakes as on the ridges.

Solar radiation measurements at Soviet Drifting Stations NP-4 and NP-6 in 1956 and 1957 (Briazgin 1959) indicate that the albedo of melting sea-ice averages 60 per cent and the albedo of melt-water pools 1-4 feet deep averages 20-22 per cent. This would cause about three times the amount of ablation under melt-water pools as on the non-water covered sea-ice. At the U. S. Drifting Station A, Untersteiner (1961) found that the average albedo of clean, melting sea-ice with a disintegrating surface lies between 62 and 70 per cent; also, he noted that the amount of ablation below melt-water pools was twice the amount for "dry" surfaces during the summer of 1957 and more than 3 times the amount during the summer of 1958.

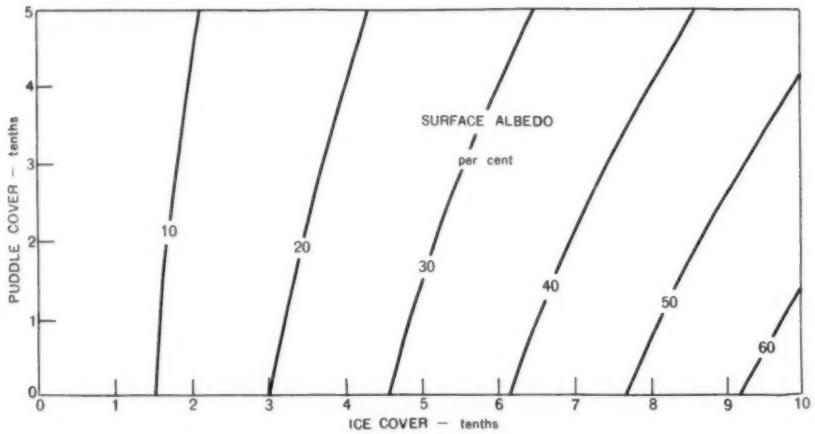



**Fig. 2.** Surface albedo versus ice and puddle cover.

## Albedo vs. ice and puddle cover

It is possible to show the most probable relation between ice cover, puddle cover, and surface albedo by assuming the following: (a) the average albedo of 8.5-tenths ice cover is 40 per cent; (b) this ice is 5-tenths covered with pools of melt water; (c) the difference between the albedo of pools and ice is 38 per cent.

$$A = I\ (65 - 3.8P)/10 \qquad (1)$$

Where: A = the albedo, expressed in per cent,
I = the fraction of total area covered with ice, expressed in tenths, and
P = the fraction of ice covered with puddles, expressed in tenths.

This equation shows that if the ocean were completely covered with melting sea ice, the albedo could range from 65 to 46 per cent as the proportion of puddles ranged from zero to 5-tenths (assumed maximum value). The albedo values corresponding to all possible ice and puddle cover values are shown in Fig. 2.

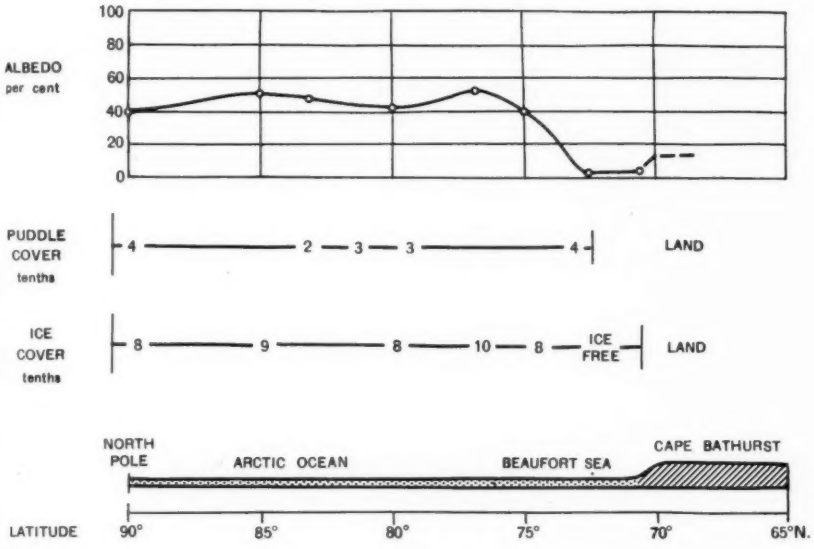



**Fig. 3.** Surface albedo, ice and puddle cover along a line from Cape Bathurst, N.W.T., Canada, to the North Pole, based on ice and puddle cover observations in July and August 1948 and albedo observations in July and August 1958.

## Meridional variation of albedo

The 375th Weather Reconnaissance Squadron USAF, in collaboration with the U. S. Navy Hydrographic Office, conducted a study in 1948 to determine the gross features of the ice pack between Alaska and the North Pole. Both visual and photographic observations of the ice were made on weather reconnaissance ("Ptarmigan") flights from Fairbanks, Alaska past Prince Patrick Island to the North Pole and return. The data were summarized and published by the Hydrographic Office (USNHO 1949) as a preliminary study of the features of sea-ice in the Arctic Ocean. Fig. 3 is prepared from these data and shows, in a section from the North Pole to Cape Bathurst, N. W. T., Canada, the gross features of ice and puddle cover during the melt season of 1948. Also shown are the albedo values that were calculated with Equation (1) to correspond with the ice and

puddle cover observations. The albedo of open water is 4 per cent from Cape Bathurst to the beginning of the pack ice near 72° N. From that point the albedo increases rapidly to a maximum of 52 per cent near 77° N. due to a greater concentration of small and medium floes. Another maximum of 52 per cent is found near 85° N. where a minimum of puddle cover (2-tenths) was observed. The albedo in the vicinity of the Pole itself was 40 per cent.

If only the gross features of the surface along the section from the Pole to 72° N. (Fig. 3) are considered, the albedo ranges from 40 to 52 per cent. If an average ice cover of 8.5-tenths and puddle cover of 3-tenths is assumed, the average albedo along this section is 46 per cent. Sverdrup (1933) has estimated that the albedo of the Arctic Ocean during summer melt conditions is between 60 and 65 per cent. It should be remembered that the standard deviation of the airborne measurements is quite large; therefore, on the basis of these measurements it cannot be stated that Sverdrup's figure is incorrect. In addition, Schwarzacher (1959) has shown that the summer ablation can vary greatly from year to year; the floe on which U. S. Drifting Station A was located had almost no ablation in 1951, whereas nearly 1 metre of ice was lost in 1955. As ice thickness, ablation, and puddle cover from which Sverdrup derived his higher albedo may have been quite different in the vicinity of the *Maud* in 1923, the lack of agreement is understandable.

## Arctic heat budget and ablation

### Ice island

In examining the surface heat budget of T-3 for the summer of 1953, Fritz (1958) points out difficulties in reconciling heat budget calculations with surface ablation observations if an albedo of 75 per cent is assumed. Much of the solar radiation penetrates the ice surface causing internal melting rather than ablation of the ice surface (Untersteiner 1961). Therefore, heat budget calculations and surface ablation observations need not necessarily agree and the albedo value of 75 per cent for Ice Island T-3 may not necessarily be incorrect.

### Sea-ice

With regard to surface ablation, only the albedo of the ice floes themselves is of interest. The relation in equation (1) shows that the average albedo of the floes (no open water) with 3-tenths puddle cover is 54 per cent along the section from Cape Bathurst to the Pole. This value has a possible significance in Arctic heat budget calculations.

Using an albedo of 66 per cent for pond-free ice, Untersteiner (1961) determined a net radiation of $+134$ cal. cm.$^{-2}$ day$^{-1}$ for maximum melting conditions in the Arctic. Assuming an albedo of 60 per cent as representative for melting sea-ice, the author (1961) determined that during July the net radiation of sea-ice averages about $+135$ cal. cm.$^{-2}$ day$^{-1}$. A comparison of the radiation fluxes is given in Table 3. The reason for the close

agreement between net radiation values calculated using these differing albedos is that resulting differences in net solar radiation are compensated by differences in the net terrestrial radiation.

**Table 3.** Comparison of arctic ice floe radiation budgets.

| *Radiation fluxes* cal. cm.$^{-2}$ day$^{-1}$ | *Assuming albedo of 60 per cent, from Hanson (1961). Period: July 1-31. Average sky cover: 6.7 tenths* | | *Assuming albedo of 66 per cent, from Untersteiner (1961). Period: July 10-23. Average sky cover: 9.4 tenths* | | *Assuming albedo of 54 per cent, as representative of the area from Cape Bathurst, N.W.T. to the North Pole* | |
|---|---|---|---|---|---|---|
| Incident solar radiation | 524 | | 416 | | 416 | |
| Reflected solar radiation | 314 | | 274 | | 225 | |
| Net solar radiation | | +210 | | +142 | | +191 |
| Atmospheric radiation | 578 | | 652 | | 652 | |
| Surface radiation | 653 | | 660 | | 660 | |
| Net terrestrial radiation | | − 75 | | − 8 | | − 8 |
| Net radiation | | +135 | | +134 | | +183 |

In discussing components of the arctic heat budget, Untersteiner (1961) has shown that during melting conditions the sensible and latent heat fluxes at the surface are about an order of magnitude smaller than the net radiation. Also, a small gain of sensible heat (+9 cal. cm.$^{-2}$ day$^{-1}$) is compensated by a small loss of latent heat (−11 cal. cm.$^{-2}$ day$^{-1}$). As a result, most of the net radiation is available for surface ablation, heating and internal melting of the ice. Untersteiner found that during a 14-day period of July 1957, 62 per cent of this energy was realized as surface ablation and 38 per cent as internal heating and melting.

If an albedo of 54 per cent, as determined from the Cape Bathurst-Pole section, is applied to Untersteiner's values, as shown in Table 3, the net radiation for maximum melt conditions would be +183 cal. cm.$^{-2}$ day$^{-1}$. If the same meteorological conditions continued during the month of July, the energy available at the surface would total about 5670 cal. cm.$^{-2}$ and it is reasonable to expect there would be a total surface ablation of nearly 50 cm. during the month and about 2100 cal. cm.$^{-2}$ would be used for internal warming and melting of the ice.

## Concluding remarks

The albedo information in this study suggests that the albedo of melting shelf-ice (not including puddles) is about 77 per cent whereas the albedo of melting sea-ice (not including puddles) is about 65 per cent. This indicates that under similar conditions the ablation of sea-ice is greater than

the ablation of shelf-ice by a factor of 1.5. Unfortunately, this cannot be confirmed by past observations as ice floe and ice island data have been gathered over widely scattered parts of the Arctic Ocean under differing radiation conditions. However, the measurements that are available indicate that the average ice island and ice floe ablation is about the same (Crary 1960, Schwarzacher 1959), although the amount of summer ablation may vary from year to year.

## References

Briazgin, N. N., 1959. The problem of the albedo on the surface of drifting ice. Probl. Arkt. i Antarkt. No. 1:33-39 [Translated for Geophysics Research Directorate, Air Force Research Division by Am. Meteor. Soc. on contract AF 19(604)6113].

Crary, A. 1958. Arctic ice island and ice shelf studies. Part I, Arctic 11:3-42.

Crary, A. 1960. Arctic ice island and ice shelf studies. Part II, Arctic 13:32-50.

Dogniaux, R., and R. Rastiels. 1955. Techniques modernes de mesure de l'éclairement énergétique solaire. Inst. Roy. Met. Belg., Publ. B. No. 16:1-47.

Fritz, S., 1958. Solar radiation measurements in the Arctic Ocean. Polar Atmosphere Symposium, Part I, Meteorology. AGARDograph No. 29:159-66.

Hanson, K. J., 1961. Some aspects of the thermal energy exchange on the south polar snowfield and arctic ice pack. Monthly Weather Review. 89:173-7.

Hattersley-Smith, G., 1957. The rolls on the Ellesmere ice shelf. Arctic 10:32-44.

Robinson, G., 1958. Some observations from aircraft of surface albedo and the albedo and absorption of clouds. Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 9:28-41.

Schwarzacher, W., 1959. Pack ice studies in the Arctic Ocean. J. Geophys. Res. 64:2357-67.

Sverdrup, H. U. 1933. Meteorology. Part I, Discussion. The Norwegian North Polar Expedition with the "Maud". 1918-25. Scientific Results, Vol. II:108. Bergen: Geofysiks Institutt.

Untersteiner, N., 1961. On the mass and heat budget of arctic sea ice. Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie A, 2:151-82.

U. S. Navy Hydrographic Office Technical Report No. 66. 1959. Report of the ice observing and forecasting program, 1958.

U. S. Navy Hydrographic Office. 1949. Preliminary study of the features of sea ice in the Arctic Ocean between April and September 1948.

# NOTES

## THE CHLOROPHYLL CONTENT OF ARCTIC SEA-ICE

A number of observers (see, e.g., ref. 1, 2), working in arctic and antarctic waters, have commented on the discoloration of sea-ice caused by unicellular algae, mainly diatoms, that are frozen into the ice. The discoloration is usually seen when the ice is broken and overturned, because it occurs principally on the lower surface of the ice and occasionally on its sides. The brown or greenish-brown colour is due to the chloroplasts in the algae and undoubtedly indicates the presence of a potential source of food in polar seas in addition to the phytoplankton and the benthic algae.

The algae associated with the ice present interesting problems concerning the adaptation of protoplasm to life under conditions of low temperatures (maximum about −1.68°C.) and of the adaptation of photosynthetic activity to low light intensities. Although they have been frequently observed, these algae have been very little studied, partly on account of collecting difficulties. Investigations of algae frozen into sea-ice have been started at the Devon Island station (75° 42′N.) of the Arctic Institute and some preliminary results are reported here.

All samples were taken about 200 yards from shore from level, undisturbed ice, which was about 65 inches thick and covered with 8.0 to 9.5 inches of snow until June 12. At that date the snow began to melt and almost all of it had disappeared by June 20. The sea, within a radius of at least 30 miles, was covered everywhere with similar amounts of ice and snow. The minimum depth of water in the sampling area was 16 feet.

Samples were collected by coring with a 3-inch-diameter SIPRE ice corer. Until June 26 the bottom of the core had a characteristic pattern of narrow and very regular parallel ridges, which were approximately 2 mm. high, 0.2 mm. wide, and spaced about 0.9 mm. The ridges were the most intensely brown part, the colour faded gradually until the ice was colourless and clear at about 1.5 inches from the bottom.

The entire coloured part of each suitable core was melted in a polyethylene container and the volume of water measured. Either the whole sample or a large aliquot was filtered through an HA millipore filter and the pigments were extracted for at least 20 hours with 5 ml. of 90 per cent acetone in the cold and dark. The sample was then hand-centrifuged and the optical density of the extract measured in a Klett-Summerson photoelectric colorimeter with a No. 66 red filter. I follow Wright[3] in assuming that 1 Klett unit equals approximately 0.28 mg. chlorophyll *a* per m.[3]. The results of the measurements, which are listed in Table 1, show that the chlorophyll concentrations are very large, as can be seen from comparison with the values in Table 2. Ryther[4] has discussed the relative primary plankton productivity of oceanic and coastal waters and pointed out that, although the values may be similar per area of sea surface, the shallow coastal waters with a denser concentration of phytoplankton offer more favourable feeding conditions to zooplankton. The high concentration of algae under sea-ice would seem to provide abundant food for the amphipods that are a conspicuous part of arctic marine life. English[2] reports that "amphipods have been observed to graze along the bottom and sides of ice floes,

appearing to wear away small areas of the ice." It is interesting to note that on June 9 for the first time the corer brought up many very small amphipods who were presumably feeding on the attached algae. It is possible that newborn amphipods find their first food on the bottom of the ice and that they either stop feeding or change to plankton feeding when the ice disintegrates.

**Table 1.** Chlorophyll *a* concentrations ($\mu$g./l.) from snow-covered sea-ice.

| *Date* | *Klett units* | *Chlorophyll* a |
|---|---|---|
| June 4 | 165 | 46.2 |
| June 5 | 444 | 124.0 |
| June 6 | 480 | 150.4 |
| June 7 | 243 | 68.0 |
| June 9 | 474 | 132.7 |
| June 11 | 164 | 45.9 |
| June 12 | 378 | 104.8 |
| June 13 | 160 | 44.8 |
| | | average 89.6 |

The large chlorophyll values imply that the algae require large amounts of nutrient salts, such as nitrates and phosphates. Several measurements of phosphate concentration in sea-ice have been made, using the standard ammonium molybdate method. Samples from five levels in each of several cores were analyzed. The lowest section of each core was, after melting, filtered through Whatman No. 2 filter paper in order to remove the algae before analysis. The amounts of phosphate varied rather irregularly through the central part of the cores and averaged about 0.5 $\mu$g.A $PO_4$-P per l. At the bottom of the cores they varied from about 1.0 to 3.0 $\mu$g.A $PO_4$-P per l. These amounts are large and if available for use by the algae frozen into the ice would support high chlorophyll concentrations.

In addition to the foregoing work a simple experiment was made in order to determine the effect of increased light intensity on the chlorophyll concentration at the lower surface of the ice. On June 3 a 10-foot square of ice was cleared of snow. The results of the measurements of chlorophyll made after June 9 are shown in Table 3. It was obvious while taking the cores that much less chlorophyll was present under the cleared area. The brown colour at the bottom of these cores was only about one-fifth as intense or less as that of the cores taken from the snow-covered ice. The most intense colour in the cores from the clear area occurred only in small flecks between the ridges, which were much reduced in size and distinctness. All cores from the cleared area had the same appearance.

**Table 2.** Chlorophyll *a* concentrations ($\mu$g./l.) from several areas.*

| *Locality* | *Chlorophyll* a |
|---|---|
| N.W. Atlantic Ocean, | |
| 4 northern stations | 2.1 |
| 14 tropical stations | 1.0 |
| Long Island Sound, | |
| March-May 1952 | 7.2 |
| East Sound, Washington | 15.0 |
| Gulf of Alaska | 2.5 |
| Woods Hole Harbor, | |
| Massachusetts | 3.35 |
| | 1.69 |
| | 2.80 |
| Allen Bay, Cornwallis Island, | |
| N.W.T. | 1.38 |

*With the exception of the last value, this table was taken from Table 2 of ref. 6. Full references may be found in that paper. The value from Allen Bay is an average of my unpublished data.

**Table 3.** Chlorophyll concentrations ($\mu$g./l.) from cleared sea-ice.

| *Date* | *Klett units* | *Chlorophyll* a |
|---|---|---|
| June 10 | 63 | 17.6 |
| June 10 | 61 | 17.1 |
| June 11 | 58 | 16.2 |
| June 12 | 78 | 21.8 |
| June 13 | 38 | 10.6 |
| | | average 16.6 |

A second area was cleared on June 10, the chlorophyll concentration was measured on the 16th, and the results confirmed the first test.

Further measurements of the ice-bound chlorophyll concentrations were made during and after the natural melting and the disappearance of the snow

cover. The results are listed in Table 4 and they show a marked decrease from the earlier values. In these samples the parallel ridges generally maintained their characteristic appearance until June 23, when they became rather indistinct, but they did not disappear almost completely as they did on the ice from artificially cleared areas.

The decrease of chlorophyll concentration as a result of increased light intensity may have either a biological

**Table 4.** Chlorophyll *a* concentrations ($\mu$g./l.) in sea-ice after snow melt.

| *Date* | *Klett units* | *Chlorophyll a* |
|---|---|---|
| June 20 | 60 | 16.8 |
| June 20 | 98 | 27.4 |
| June 23 | 24 | 6.7 |
| June 26 | 30 | 8.4 |
| June 27 | 28 | 7.8 |
| June 27 | 18 | 5.0 |
| | average | 12.0 |

or a physical cause. It is well known that unicellular algae have optimal light intensities for growth and can be inhibited by excessive light through photo-oxidation of their photosynthetic pigments. This may be the biological basis for the decrease of chlorophyll in the present work.

The effect of light on the structure of the ice itself must also be considered. The structure of sea-ice has been examined by Weeks [5] who states that "Sea ice crystals, therefore, consist of alternating layers of pure ice and brine. . . . The distance between the planes of brine inclusions varies from 0.2 to 0.8 millimeters and averages 0.45 millimeters. . . . In a cross section of a growing sheet of sea ice [*in*] the lower 2.8 centimeters . . . the ice platelets that make up the single crystals are completely separated by layers of brine." It seems clear that in the cores from snow-covered ice at Devon Island the main growth of algae occurred on the platelets of pure ice described by Weeks. The cores taken from the cleared ice showed very much reduced and indistinct ridges or platelets, and it is quite possible that their disintegration is the cause of the disappearance of the algae. By acting as a heat absorber the algae themselves could cause the break-down of the platelets and thus destroy their own micro-habitat.

During the natural melting of the snow, however, the ice ridges or platelets persisted in their characteristic form after the chlorophyll concentration had decreased. It would thus appear that physiological inhibition is the main cause of the disappearance of the pigment from sea-ice.

The question of how much light reaches the underside of sea-ice is particularly interesting. In the latitude of the Devon Island station the sun is above the horizon continuously from about April 20 to August 20. In May and early June of 1961 the sky was generally clear and the weather bright. The full solar radiation program of the station was not yet under way when this note was written, but a few spot readings indicate that at noon about 90 per cent of the total radiation was reflected from the surface of the snow. Further, when values of about 3600 foot-candles were measured at the snow surface at noon, no more that 50 foot-candles penetrated 9 inches of snow, the density of which was 0.3 gm./cm.$^3$. Ryther and Yentsch[6] give 100 foot-candles as the intensity at which the photosynthetic production of energy just balances the energy requirements of a general phytoplankton population in temperate regions. It is thus evident that algae under snow and ice receive far less than the minimal amount of light required by phytoplankton of temperate regions. These algae living on the underside of the ice must therefore be adapted to carry out photosynthetic activities and to grow under much reduced light intensities and they would probably be completely inhibited by intensities in which algae of temperate zones normally flourish.

I wish to acknowledge the assistance of and profitable discussions with Mr. Brian Beck in the course of this work.

SPENCER APOLLONIO
Devon Island Expedition
of the Arctic Institute

[1]Bursa, A. 1961. Phytoplankton of the *Calanus* expeditions in Hudson Bay, 1953 and 1954. J. Fish. Res. Bd. Can. 18:51-83.

[2]English, T. S. 1959. Primary production in the central north polar sea, Drifting Station Alpha, 1957-58. Pap. pres. 1st Internat. Oceanogr. Congr., New York, 1959. Unpubl. MS.

[3]Wright, J. C. 1958. The limnology of Canyon Ferry Reservoir. I. Phytoplankton-zooplankton relationships in the euphotic zone during September and October 1956. Limnol. and Oceanogr. 3:150-9.

[4]Ryther, J. H. 1961. The plankton ecology, related chemistry and hydrography of the Sargasso Sea. Part 2. Geographic variations in productivity. Final Rept. U.S. Atom. En. Comm. Contract AT (30-1)-2078. Bermuda Biol. Sta. Mimeogr. 58 pp.

[5]Weeks, W. F. 1958. The structure of sea ice: A progress report. *In:* Arctic Sea Ice. NAS-NRC Pub. 598:96-9.

[6]Ryther, J. H., and C. S. Yentsch. 1957. The estimation of phytoplankton production in the ocean from chlorophyll and light data. Limnol. and Oceanogr. 2:281-6.

**Sir Hubert Wilkins Memorial Arctic Expedition, 1962**

Scientists interested in joining a group now forming to work on the glaciers and mountains of the Greely Fiord, Eureka Sound area from June 1 to June 29, 1962 are invited to send details and an outline of the work contemplated to: Clarence E. LeBell, 16 Alden Road, Peabody, Mass., U.S.A.

# INSTITUTE NEWS

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No. 6 of this series, THE MEDUSAE OF THE CHUKCHI AND BEAUFORT SEAS OF THE ARCTIC OCEAN INCLUDING THE DESCRIPTION OF A NEW SPECIES OF *ENCODONIUM* (HYDROZOA: ANTHOMEDUSAE). By Cadet Hand and Lai Bing Can, 23 pages, 7 tables, 9 figures, has appeared. Copies can be obtained from the Montreal Office at the price of $0.50 to members, $1.00 to non-members.

**Change of address — Montreal Office**

In early October the Montreal offices of the Arctic Institute of North America will be moved to a new address at 3458 Redpath Street, Montreal 25. The present site, lent by McGill University since 1948, has been sold and the existing building will be demolished to make way for a new structure.

# REVIEW

ABANDONED. THE STORY OF THE GREELY ARCTIC EXPEDITION, 1881-1884.

By A. L. Todd. Introduction by Vilhjalmur Stefansson. *New York: McGraw-Hill Book Company, Inc. 1961. 8½ x 5¾ inches. xx + 323 pages, 2 maps, numerous illustrations. $5.95.*

Among polar expeditions that were marred by tragedy, Greely's Lady Franklin Bay expedition occupies a peculiar position. It seems to have left a weaker impression than many others, yet it ranks as one of the most remarkable in the annals of polar exploration. There is also more firsthand information about it; in almost no other case, in fact, is the story so complete. By way of contrast, there were no survivors of the last Franklin expedition, and only the sketchiest of records and remains were ever found. Similarly none of Scott's polar party lived to tell the tale. No one knows, even today, what happened to some of those aboard the "Jeannette" and the "Karluk"; and the fate of Andrée's party, whose bodies were found after a lapse of 33 years, can only be surmised. Among the older tragedies, there are similar elements of uncertainty or incompleteness in the accounts of such as Willoughby, Barents, Knight, and Hudson. But the story of Greely and his men is known quite thoroughly from start to finish. They recorded their activities in copious detail, and these records, both public and private, have been preserved. No member of the expedition died in circumstances not reasonably well accounted for, since survivors and doomed were together until the end; and the relief expedition brought back not only the former but also the bodies of most of the latter.

It is perhaps this abundance of information, and the relative absence of the unexplained, that has induced the apparent feeling that the curtain has been finally rung down on the Greely story. One may concede that original diaries and journals do speak with a special vitality, and even finality — at least for those who read them. But few people do read them, and thus it is well that occasionally efforts are made to resurrect and reconstruct such stirring tales for the interest of the reading public. During the past year two notable attempts have been made to revive the Greely story, first "The Long Rescue", by Theodore Powell, and more recently "Abandoned", by A. L. Todd.

In "Abandoned" Mr. Todd draws heavily on the voluminous records mentioned above, but he has also had the benefit of access to previously unavailable material in private hands, including papers of several members of the expedition, notably Greely, Brainard, Pavy, and Rice. He has also attempted to do what diaries and records cannot do — namely to incorporate in his narrative the story of the expedition from the point of view of the world outside, principally the efforts to organize relief expeditions and the reactions of press and public when the survivors returned. At the beginning there is a brief description of the background of the expedition and its personnel, and at the end he tells briefly what happened to the survivors afterwards. It seems to me that considering the scope of his undertaking the author has succeeded about as well as one can expect within the confines of a single volume of moderate size.

The Lady Franklin Bay expedition was the principal American contribution to the First International Polar Year of 1882-3, in which eleven nations established fifteen observatory stations in the polar regions, two or three in the

Antarctic and the rest in the Arctic. Thirty-four permanent observatories also took part. The project was the realization of a vast concept of cooperative international scientific research in these regions, initially presented by Karl Weyprecht in 1875 to a scientific conference at Graz, and adopted and developed in later conferences at Rome and Hamburg in 1879 and Bern in 1880. This pioneer effort provided a great deal of useful information and served as a model for the Second International Polar Year in 1932-3 and the International Geophysical Year in 1957-8. The Lady Franklin Bay expedition had the most northerly location (81° 44′N.), and was the most interesting, since it had the additional appeal of an attempt to reach a new "farthest north". As events turned out, it was also the most unfortunate.

Initially a semi-private project, it was officially taken over by the American government early in 1881. The officer appointed to command, First Lieutenant A. W. Greely, was a strait-laced New Englander with some twenty years of service in the Cavalry and Signal Corps, including experience in the Civil War and later in establishing telegraphic communications in the West. He lacked firsthand knowledge of the Arctic, as, for that matter, did almost all the men chosen to accompany him. Nevertheless for two years success attended the expedition and a great deal was accomplished. At Discovery Harbour in Lady Franklin Bay, which was reached with relative ease in August 1881, the party of twenty-five (three officers, one contract surgeon, two Greenland Eskimos, the rest army N.C.O.'s and privates) established Fort Conger, and from this base a series of sledging expeditions reached a new "farthest north" at 83° 24′N., revealed new stretches of the north Greenland and Ellesmere Island coasts, and examined large parts of the Ellesmere Island interior. All the while a great amount of scientific data was being gathered in accordance with the original plan.

Since expected relief did not arrive in the summer of 1882, a second winter had to be spent at Fort Conger in complete isolation but relative comfort, and then, in August 1883, when it seemed apparent that again no ship would reach them, Greely somewhat doubtfully gave the order to retreat. This was in accordance with instructions that he should abandon Fort Conger no later than September 1, 1883, and retire to the southern extremity of Kane Basin, where either a relief ship or supplies would be found. It meant leaving a good building and considerable food supplies, supplemented by natural resources of fuel and game animals, for a difficult retreat by boat and ice floe, late in the season and over a dangerous route, to an uncertain rendezvous in a vaguely defined place. Their worst fears were realized, and when they finally managed to complete their wearing journey, it was only to learn that the 1882 relief ship had turned back, the 1883 ship had been crushed in the ice and sunk, the two expeditions together had left them only some 1,000 rations out of 50,000 carried, and with winter upon them they were left to their own resources with rations for only about 45 days.

At Camp Clay, on the north shore of Pim Island, they set up a winter shelter as best they could, husbanded their scanty food supply with drastic economy, and in increasingly desperate circumstances struggled to survive the winter. Miraculously there was only one death before April, but then, with supplies virtually exhausted, the hunt a failure except for a polar bear, a seal, a few foxes, and birds, and otherwise nothing to sustain life but shrimps, seaweed, tripe-de-roche, saxifrage, and sealskin, death finally took its toll. When Commander Schley arrived with two relief ships on June 22, 1884, after a determined struggle to reach them, only Greely and six others remained alive in their ghastly death hole west of Cape Sabine. All the rest had died of starvation and exposure, except two — an Eskimo who had drowned and a private who had been shot, at Greely's order, for persistently stealing food.

This is the substance of Mr. Todd's

story, and it is extremely well told, showing obvious effects of thorough research and being liberally fortified with quotations from the diaries of members of the expedition and from contemporary records. He concentrates on the final disastrous ten months after the abandonment of Fort Conger, giving only about 65 of 315 pages to the more than two years preceding. Little attempt is made, as he frankly admits, to describe in detail the scientific work of the expedition, or even the more exciting sledge journeys into hitherto unknown regions. It is essentially the record of "the physical and moral courage displayed by a small group of men abandoned to hunger and cold". As the narrative unfolds heroes emerge, notably Sergeant Brainard and Private Frederick, two of the survivors, whose behaviour was impeccable throughout, and who strove unselfishly to the last to provide for their comrades. Another was the Canadian George W. Rice, who was from the start the inspiration of the group, and who came into his own, after a somewhat irresponsible beginning, as a natural leader and the expedition's indispensable man, until he met his end trying to recover a small cache from Baird Inlet. Inevitably, too, there were lesser men, and at least one downright scoundrel. The result was a certain amount of dissension and insubordination, although Greely always maintained afterwards that considering the horrors they faced the typical atmosphere was one of remarkable co-operation, mutual sympathy, and good will. Greely himself is revealed as an intelligent, meticulous, resourceful commander, doubtless lacking in tact and judgment upon occasion, but always alive to his responsibilities and demonstrating remarkable qualities of moral leadership and stubborn determination during the last dreadful months at Camp Clay.

The author's presentation is detached and fair, and while maintaining throughout a restrained approach, he makes no attempt to gloss over unpleasant aspects of the expedition, or those that reflect unfavourably upon particular individuals. Conspicuous here are the running disagreements between Greely on the one side and Dr. Pavy and Lt. Kislingbury on the other, and also the touchy subject of cannibalism during the final stages, which was revealed all too plainly when some of the dead bodies were discovered and, of course, proved publicly and conclusively when they were taken home. Mr. Todd indulges in little direct criticism of the men for weakness or wrongdoing, preferring to rely upon their comments about each other in their diaries. But he is less inhibited when he speaks of the blundering and politicking in Congress and elsewhere in connection with the dispatch of relief expeditions; and he pours vituperation upon the contemporary press for its sensational reaction to the rumours of cannibalism before any facts had been confirmed — a display of journalistic irresponsibility and shallowness that would, judging by his account, be hard to surpass.

Serious flaws are hard to find. It would be unreasonable to ask for thorough documentation in a book of this kind, no doubt, but all the same I think the author would have done well to identify more clearly the new material he has incorporated in his work. There are a few minor slips in fact and perhaps in judgment, e.g., on page 21 "land of two hemispheres" is hardly correct for Greenland and Ellesmere Island; there is evidently some confusion on page 293, where three different versions, apparently emanating from the same source, are given of Dr. Pavy's death; and it does not seem worthwhile or relevant to take note (page 288) of the thief who followed the Greely parades. But such things are of small importance, and it would be uncharitable, to say the least, to pretend that they detract seriously from the overall great merit of the book. Personally I do not think that full justice can be done to the Greely story in 300 pages, but insofar as it can be, Mr. Todd has done it exceptionally well.

GORDON W. SMITH

# GEOGRAPHICAL NAMES IN THE CANADIAN NORTH

The Canadian Board on Geographical Names has adopted the following names and name changes for official use in the Northwest Territories and Yukon Territory. For convenience of reference the names are listed according to the maps on which they appear. The latitudes and longitudes given are approximate only.

**Chart 7676 Bernard Harbour**
*(Adopted March 3, 1960)*

| | | | |
|---|---|---|---|
| Bernard Creek | 68°47′N. | 114°48′W. | |
| Desbarats Point | 68°47′ | 114°46′ | |
| Alaska Point | 68°47′ | 114°46′ | |
| Teddy Bear Island | 68°47′ | 114°46′ | |
| North Star Point | 68°47′ | 114°46′ | |
| Cub Islet | 68°47′ | 114°44′ | |
| Cox Island | 68°47′ | 114°44′ | |
| Chipman Point | 68°47′ | 114°43′ | |
| Burwash Point | 68°46′ | 114°46′ | |
| Sweeney Island | 68°46′ | 114°45′ | |
| Merritt Point | 68°46′ | 114°46′ | |
| Fuller Point | 68°46′ | 114°44′ | |
| *Rescinded* | | | |
| Bernard (settlement) | 68°47′ | 114°49′ | |

**Sans Sault Rapids 106 H**
*(Adopted July 7, 1960)*
*Name confirmation*

| | | | |
|---|---|---|---|
| Rainbow Arch (cliff) | 65°27′N. | 128°13′W. | |

**Chart 7053 Padloping Island to Clyde Inlet**
*(Adopted August 4, 1960)*

| | | | |
|---|---|---|---|
| Eglinton Fiord | 70°46′N. | 69°50′W. | |
| Ravenscraig Harbour | 70°42′ | 69°42′ | |
| Tanner Bay | 68°23′ | 66°57′ | |
| Delight Anchorage | 67°02′ | 62°43′ | |
| Esquimaux River | 70°40′ | 69°43′ | |
| Kogalu River | 70°42′ | 69°01′ | |
| Erik Point | 70°52′ | 69°55′ | |
| Cape Eglinton | 70°47′ | 69°30′ | |
| Isabella Bank | 69°27′ | 64°58′ | |
| Alexander Bank | 69°04′ | 64°29′ | |
| Satigsun Island | 68°32′ | 66°51′ | |
| Nudlung Island | 68°20′ | 67°01′ | |
| Sledge Pointers (hills) | 70°32′ | 69°12′ | |
| Sawtooth Mountain | 70°25′ | 68°54′ | |
| Alexander Bay | 69°06′ | 67°30′ | not Alexander Inlet |
| Pitchforth Fiord | 68°56′ | 68°00′ | not Pitchforth (Akojartung) Fiord |
| Cape Aston | 70°00′ | 67°05′ | not Aston Point |
| Idjuniving Island | 67°54′ | 64°39′ | not Idjuniving (island) |
| Kekerturnak Island | 67°52′ | 64°46′ | not Kekerturnak (island) |
| Durban Island | 67°05′ | 62°12′ | not Durban (Aggidjen) Island |
| *Name confirmations* | | | |
| Nudlung Fiord | 68°19′ | 67°10′ | not Nuluk Fiord |
| Nedlukseak Fiord | 68°00′ | 66°06′ | not Nedludseak Fiord |
| *Altered application* | | | |
| Maktak Fiord | 67°19′ | 64°12′ | not Maktartudjennak Fiord nor Muktuk Fiord |

*Rescinded*

| | | | |
|---|---|---|---|
| Padle (settlement) | 66°59′ | 62°37′ | |
| Ijellirtung Fiord | 69°20′ | 68°42′ | |

**Flat River 95 E**
*(Adopted September 1, 1960)*

| | | | |
|---|---|---|---|
| Hot Springs Valley | 61°56′N. | 127°22′W. | |
| Hole in the Wall Lake | 61°47′ | 127°16′ | |
| Rabbitkettle Lake | 61°57′ | 127°13′ | |
| Rabbitkettle River | 61°57′ | 127°09′ | |
| Rabbitkettle Hotsprings | 61°56′ | 127°10′ | |
| Hole in the Wall Creek | 61°57′ | 127°09′ | |

**Quiet Lake 105 F**
*(Adopted September 1, 1960)*

| | | | |
|---|---|---|---|
| Moss Lake | 61°14′N. | 132°11′W. | not McNeil Lake |

**Mount St. Elias 115 B and C (E½)**
*(Adopted September 1, 1960)*

| | | | |
|---|---|---|---|
| Canada Creek | 60°51′N. | 138°37′W. | |
| Corwin Cliffs | 60°19′ | 140°17′ | |
| Mount Queen Mary | 60°39′ | 139°41′ | |
| Mount King George | 60°35′ | 139°44′ | |
| Mount Maxwell | 60°44′ | 138°34′ | |
| Mount Jeanette | 60°20′ | 140°43′ | |
| Mount Bering | 60°21′ | 140°36′ | |
| Mount Malaspina | 60°18′ | 140°34′ | |
| Mount Augusta | 60°13′ | 140°31′ | |
| Mount Eaton | 60°18′ | 140°20′ | |
| Mount Vancouver | 60°20′ | 139°43′ | |
| Mount Alverstone | 60°22′ | 139°02′ | |
| Mount Hubbard | 60°19′ | 139°03′ | |
| Mount Cook | 60°11′ | 139°57′ | |
| Mount Seattle | 60°05′ | 139°11′ | |
| Ogilvie Glacier | 60°44′ | 140°48′ | |
| Donjek Glacier | 60°58′ | 139°49′ | |
| Kluane Glacier | 60°54′ | 139°17′ | |
| Kaskawulsh Glacier | 60°43′ | 138°51′ | |
| Hubbard Glacier | 60°22′ | 139°27′ | |
| South Arm (glacier) | 60°39′ | 138°48′ | |
| Seward Glacier | 60°13′ | 140°21′ | |
| Agassiz Glacier | 60°14′ | 140°39′ | |
| Columbia Creek | 60°51′ | 138°43′ | |
| Dusty Glacier | 60°24′ | 138°21′ | |
| Disappointment Glacier | 60°30′ | 138°34′ | |
| Felsite Creek | 60°34′ | 138°02′ | |
| Felsite Glacier | 60°29′ | 138°21′ | |
| Atrypa Glacier | 60°36′ | 138°52′ | |
| Kaskawulsh Mountain | 60°40′ | 138°51′ | |
| Snowshoe Peak | 60°37′ | 138°19′ | |
| Chalcedony Mountain | 60°39′ | 138°12′ | |
| Airdrop Lake | 60°39′ | 138°17′ | |
| Hoodoo Mountain | 60°43′ | 138°13′ | |
| Maxwell Glacier | 60°40′ | 138°36′ | |
| Disappointment River | 60°46′ | 138°16′ | |
| Observation Mountain | 60°49′ | 138°42′ | |
| Maxwell Creek | 60°47′ | 138°21′ | |
| Lost Cache Creek | 60°49′ | 138°25′ | |
| Outpost Mountain | 60°56′ | 138°20′ | |
| Mount Cairnes | 60°52′ | 138°16′ | |
| Pinnacle Peak | 60°27′ | 138°58′ | |
| Mount Baird | 60°19′ | 140°31′ | not Mount Malaspina |
| Vulcan Mountain | 60°54′ | 138°26′ | not Mount Vulcan |
| Cascade Glacier | 60°17′ | 140°30′ | |
| Stairway Glaicer | 60°39′ | 139°00′ | not Cascade Glacier |

**Cape Smith 35 D/10**
*(Adopted October 5, 1960)*

| | | | |
|---|---|---|---|
| Inupuk Bay | 60°42′N. | 78°40′W. | |

**Nansen Sound 560 S½**
*(Adopted October 5, 1960)*

| | | | |
|---|---|---|---|
| Svartfjeld Peninsula | 80°51′N. | 88°20′W. | |
| *Name confirmations* | | | |
| Fjeldholmen Islands | 81°31′N. | 91°47′W. | not Fjeldholmen Island |
| Svartevaeg Cliffs | 81°17′ | 92°13′ | not Svortevag Cliffs |
| Hvitland Peninsula | 81°06′ | 89°54′ | not Hvitland Hills |

**Cumberland Sound 26 SW and 26 SE**
*(Adopted November 3, 1960)*

| | | | |
|---|---|---|---|
| *Altered application* | | | |
| Tawsig Fiord | 64°50′N. | 65°55′W. | |

**Henrietta-Maria 43 NE**
*(Adopted November 3, 1960)*

| | | | |
|---|---|---|---|
| Joy Island | 55°54′N. | 80°07′W. | |
| Revillon Island | 55°56′ | 80°09′ | |

**Wellington Channel 58 NW and 58 NE**
*(Adopted November 3, 1960)*

| | | | |
|---|---|---|---|
| Abandon Bay | 75°31′N. | 94°03′W. | |
| Laura Lakes | 75°13′ | 93°48′ | |
| Red Loon Lake | 74°43′ | 91°30′ | |
| Nanook Pond | 74°44′ | 91°21′ | |
| Muskox Pond | 74°43′ | 91°20′ | |
| Pressure Point | 74°00′ | 95°23′ | not Cape Pressure |
| *Name confirmation* | | | |
| Shellabear Creek | 74°45′ | 93°28′ | not Barlow Creek |

**Chart 7076 Meighen Island to Cape Discovery**
*(Adopted November 3, 1960)*

| | | | |
|---|---|---|---|
| Caledonian Bay | 79°45′N. | 82°00′W. | |

**Fort Smith-Nonacho 75 SW**
*(Adopted November 3, 1960)*

| | | | |
|---|---|---|---|
| Etthengunneh Island | 61°48′N. | 109°14′W. | (Nonacho Lake) |

**Destruction Bay 115 G/2**
*(Adopted November 3, 1960)*

| | | | |
|---|---|---|---|
| Jackson Point | 61°03′N. | 138°30′W. | |

**Barrow Strait West 68 NW and 68 NE**
*(Adopted December 1, 1960)*

| | | | |
|---|---|---|---|
| Intrepid Passage | 74°50′N. | 98°05′W. | |
| Resolute Passage | 74°49′ | 95°55′ | not St. Roch Passage |
| *Rescinded* | | | |
| Davy Island | 74°31′ | 98°05′ | |

**Bathurst Inlet 76 NW and 76 NE**
*(Adopted December 1, 1960)*

| | | |
|---|---|---|
| Bathurst Lake | 66°18′N. | 107°16′W. |
| Bear Creek Hills | 66°34′ | 107°23′ |
| Boulder Creek | 67°27′ | 107°28′ |
| Boulder Falls | 67°27′ | 107°37′ |
| Burnside Falls | 66°53′ | 108°14′ |
| Burnside Hills | 66°50′ | 108°23′ |
| Fishing Creek | 66°38′ | 107°43′ |
| Goulburn Lake | 67°19′ | 108°37′ |
| Portage Bay | 67°05′ | 108°28′ |
| Wilberforce Hills | 67°02′ | 108°34′ |
| Bellanca Rapids | 66°22′ | 110°07′ |

**Garland Lake 86 E/15**
*(Adopted December 1, 1960)*

| | | | |
|---|---|---|---|
| North Superstition Island | 65°56′N. | 118°32′W. | |
| South Superstition Island | 65°53′ | 118°33′ | not Superstition Island |

**Markham Inlet 120 N½**
*(Adopted December 1, 1960)*

| | | | |
|---|---|---|---|
| Moss Bay | 82°59′N. | 67°41′W. | |
| Sail Harbour | 82°53′ | 65°15′ | |
| Dana Bay | 82°44′ | 64°00′ | |
| Victoria Lake | 82°35′ | 63°05′ | |
| Lincoln Bay | 82°08′ | 62°00′ | |
| Ayles Point | 82°44′ | 63°45′ | |
| Sickle Point | 82°30′ | 62°05′ | |
| Floeberg Beach | 82°28′ | 61°22′ | |
| Oopik Island | 82°30′ | 63°05′ | |
| Giffard Peak | 83°00′ | 69°00′ | |
| Mount Gladstone | 82°54′ | 67°35′ | |
| Mount Disraeli | 82°55′ | 68°05′ | |
| Gable Cliff | 82°52′ | 65°25′ | |
| Mount Foster | 82°53′ | 67°20′ | |
| Bird Point | 82°53′ | 65°25′ | |
| Guide Hill | 82°45′ | 64°35′ | |
| View Hill | 82°55′ | 65°06′ | |
| Mary Peak | 82°48′ | 64°05′ | |
| Gap Mountain | 82°40′ | 64°40′ | |
| Mount Julia | 82°46′ | 64°15′ | |
| James Ross River | 82°54′ | 64°55′ | |
| Piper Pass | 82°25′ | 69°10′ | |
| Divide Glacier | 82°17′ | 68°13′ | |
| Markham Fiord | 82°59′ | 71°50′ | not Markham Bay |
| Stuckberry Point | 82°59′ | 67°10′ | not Cape Stuckberry |
| Cape Delano | 82°45′ | 63°40′ | not Delano Point<br>nor View Point |
| Mount Cooper Key | 83°07′ | 71°15′ | not Cooper Key Mountains<br>nor Cooper Key Mountain |
| Mount Grant | 82°27′ | 66°07′ | not Grant Mountain |
| Mount Parry | 82°06′ | 62°50′ | not Parry Mountain |
| *Altered applications* | | | |
| Hamilton Bluff | 82°48′ | 66°22′ | not Beverley Point |
| Hamilton Fish Peak | 82°47′ | 63°35′ | |
| *Rescinded* | | | |
| Alert Mountain | 83°02′ | 70°00′ | |
| Frere Mountain | 82°35′ | 69°45′ | |
| Mount Rawlinson | 82°38′ | 68°45′ | |
| Cape Rawson | 82°25′ | 61°20′ | |
| Giffard Point | 83°00′ | 68°40′ | |
| Black Cape | 82°20′ | 61°05′ | |

**Chart 5470 Belcher Islands**
*(Adopted January 19, 1961)*

| | | | |
|---|---|---|---|
| *Altered application* | | | |
| Snape Island | 55°43′N. | 79°19′W. | |
| *Rescinded* | | | |
| French Island | 55°48′ | 79°13′ | |

**Chart 7670 Bernard Harbour to Lady Franklin Point**
*(Adopted January 19, 1961)*

| | | | |
|---|---|---|---|
| Cache Point Channel | 68°37′N. | 113°36′W. | |
| Waldron Islands | 68°52′ | 114°54′ | |
| Harkness Island | 68°55′ | 114°26′ | |
| Banksland Islet | 68°56′ | 114°21′ | not Shaw Islet |
| Bowers Island | 68°38′ | 113°47′ | not Anchors Island<br>nor Nell Island |
| Ivonayak Island | 68°28′ | 113°46′ | not Duck Island |
| Becher Point | 68°28′ | 113°16′ | not Pierre Point |

**Sibbeston Lake 95 G**
*(Adopted January 19, 1961)*

| | | | |
|---|---|---|---|
| Jackfisch Ridge | 61°03′N. | 123°55′W. | not Jackfish Mountains |
| Dehdjida Island | 61°14′ | 122°43′ | not Long Island<br>nor Drill Camp Island<br>nor Deh-Djida Island |
| Dehdjida Creek | 61°15′ | 122°37′ | not Det-She-Da Creek |
| Nizone Creek | 61°45′ | 122°45′ | not Nu-So Creek |

**Flat River 95 E**
*(Adopted January 19, 1961)*
*Name confirmation*

| | | | |
|---|---|---|---|
| Ragged Range | 61°44′N. | 127°15′W. | not Cathedral Range<br>nor Batholith Range<br>nor Nahanni Batholith Range<br>nor Snyder Range |

**Lac Des Bois 96 K**
*(Adopted January 19, 1961)*
*Name confirmation*

| | | | |
|---|---|---|---|
| Hare Indian River | 66°18′N. | 128°38′W. | not Rabbitskin River |

**Porcupine River 116 NW and 116 NE**
*(Adopted January 19, 1961)*
*Name change*

| | | | |
|---|---|---|---|
| Drifting Snow Creek | 66°29′N. | 141°23′W. | not Bern Creek |

**Carmacks 115 I**
*(Adopted February 2, 1961)*

| | | |
|---|---|---|
| Miller's Ridge | 62°07′N. | 136°37′W. |

**Cape Dyer 16 NW and 16 NE**
*(Adopted March 2, 1961)*

| | | |
|---|---|---|
| Eskimo Pass | 66°40′N. | 62°22′W. |
| Shannagh River | 66°40′ | 62°02′ |
| Blanc Mountain | 66°42′ | 61°50′ |
| Snow Gemini Peak | 66°42′ | 61°40′ |
| Moonshine Ridge | 66°41′ | 61°40′ |
| Caribou Glacier | 66°40′ | 61°47′ |
| Purgatory Valley | 66°41′ | 61°53′ |
| Snake Meadow | 66°39′ | 61°55′ |
| Rougemont Glacier | 66°35′ | 62°12′ |
| Thunder Falls | 66°40′ | 62°04′ |
| Illusion Glacier | 66°39′ | 62°07′ |
| Mount Janes | 66°38′ | 62°06′ |
| Jagged Ridge | 66°39′ | 62°09′ |

## SCIENCE IN ALASKA

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Vol. 3. ——— 1952. Proceedings of the Third Alaskan Science Conference held at Mt. McKinley National Park, Sept. 22-7, 1957. Publ. by AAAS, 1954; 221 pages, abstracts only; diagrams, charts.

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